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ABSTRACT: *Palynological study of Recent Orinoco sediments shows the relative influence of location of source area and transport by air and water currents on pollen dispersal. Distribution of fungi, cuticles, reworked material, Hystrichosphaeridae, and foraminifera have also been studied. Variations in microfossil content with depth in core samples are found to be related to depositional history. The significance of the results in palynological and paleogeographical studies of older sediments is discussed.*

Palynology of Recent Orinoco delta and shelf sediments:

Reports of the Orinoco Shelf Expedition; Volume 5

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INTRODUCTION

General remarks

Experience with palynological correlation in clastic sediments of Tertiary age has led to the conviction that water-transport of pollen grains and spores is more important than wind-transport in explaining certain distributional phenomena. The present study has, consequently, been undertaken with the primary purpose of investigating transport and deposition of pollen in an environment of predominantly clastic sedimentation. The distribution of other microfossil groups has also been studied. In the following discussion, the term "pollen" will be used as comprising both pollen grains (derived from Spermatophyta) and spores (derived from Pteridophyta).

The samples taken by the Orinoco Shelf Expedition from the Recent sediments of the Gulf of Paria and on the outer shelf north and east of Trinidad proved to be well suited to this purpose. Many samples were available for study, but because of lack of time the examination had to be restricted to a limited number only. In making the selection, the guiding principle was to obtain a regional picture. For the Gulf of Paria and the outer shelf this was possible without much difficulty, but the equally interesting Orinoco delta could only be sampled to a very limited extent, due to poor accessibility. In January, 1956, the author was able to accompany a surveying party to the eastern Orinoco delta for a period of four weeks. Transportation was by flat-bottomed launch and canoe along the main tributaries, and there were short side-trips into the back-swamp area also. Samples were collected from the river bottom, levee, and back-swamp sediments, but because of the great variety in local conditions of vegetation and sedimentation, this sampling is still very incomplete. Valuable information on the distribution of vegetation was obtained, however. The main emphasis is therefore laid on the study of the offshore sediments. Three cores, at suitably located spots on the shelf, were selected for a closer study of the vertical variations in microfossil content. Some samples were examined especially at the request of the sedimentologists, in order to check the supposed sub-Recent age. The location of all samples is plotted in text-figure 1.

In interpreting his results, the author was greatly aided by the very detailed hydrographic and sedimentological results discussed by van Andel and Postma (1954) and by Koldewijn (1958) and Nota (1958). Gratitude is further expressed to the Cía. Shell de Venezuela for permission to publish the results of the present study. Thanks are also due to Professor P. H. Kuenen, Dr. A. M. Oosterbaan, Dr. A. Ford, Dr. B. L. Meyer, and Dr. B. W. Koldewijn for valuable suggestions and for reviewing the manuscript, and to Dr. T. van Andel for encouragement and stimulating discussions during the course of the work.

In the laboratory the samples were subjected to standard chemical treatment. After drying, crushing and mixing to a uniform powder, an accurately weighed amount between 1 and 5 grams, depending upon the richness of the sample in pollen, was boiled for 20 minutes with concentrated hydrofluoric acid. When the samples contained a large amount of calcium carbonate they were pre-treated with 10 per cent hydrochloric acid. After centrifuging off the remaining hydrofluoric acid they were washed one or more times, if necessary, with hot 10 per cent hydrochloric acid to remove silica gels formed during the reaction with hydrofluoric acid. This chemical treatment is quantitative, and the next step is to measure the concentration of microfossils in the residue. For this purpose the residue was transferred to a graduated centrifuge tube and a measured amount of a mixture of glycerine and alcohol was added, varying between 1 and 10 cc., again depending upon the concentration of microfossils to be expected. The mixture was then shaken very thoroughly to obtain an even suspension. Next, two drops were taken at random with a standard pipette from the suspension, transferred to a slide, and covered with a standard-sized cover glass. The number of microfossils could then be counted, and, as the number of drops from the pipette per cubic centimeter of liquid is known, the number of microfossils per gram of dried sediment could easily be calculated. This method produced consistent results with duplicate measurements; three slides were generally counted for each sample and the average value determined.

At the same time, the percentage ratios in which pollen types and spores occur were determined. For this purpose it was often necessary to count more slides in the case of poor samples. It was difficult to concentrate pollen in these samples because, here especially, large amounts of silica gels were often formed, which could not be entirely removed by hydrochloric acid treatment, thereby greatly hampering counting.

Identification of microfossils

The residue contained a large variety of microfossils. It was not possible to study all groups equally well, and in the following discussion the main emphasis will he placed on the pollen, which served the primary aim of the study. In addition, those microfossils that have proved to be of practical interest in the study of fossil sediments have also been studied.

In the first place, the total quantity of pollen per gram of sediment was measured. Next, the percentage ratio in which the various pollen types occurred was determined. These types were differentiated at first on a morphologic basis, and were then compared with a collection of Recent acetolysed pollen slides that had been prepared from identified fresh or herbarium material. Most of the more common and interesting types could thus be identified.

The next group of microfossils recorded were the fungal spores. These were merely counted per gram, and no differentiation between types was attempted. Algal remains were very scarce. Only *Phycopeltis* was seen regularly in the delta deposits. *Pediastrium* was extremely rare, and *Botryococcus* completely absent. Hystrichosphaerids were determined, but no attempt at a detailed study was made.

The abundance of cuticles and their average sizes were estimated, but a further analysis was not made, although identification is probably possible and would have some importance for facies interpretation. Tracheid remains, reworked from older deposits, were also noted. Among the animal microfossils, only the remains of the smaller foraminifera that are left after the chemical preparation were recorded. No attempt at specific or generic identification was made, however.

ENVIRONMENT

Topography

A detailed description of the area has been given by van Andel (1954). In text-figure 1 the main features are shown, such as the llanos plains, where older Quaternary sediments form the surface; the vast alluvial plain of the Orinoco delta (also called the Delta Amacuro); the mountainous peninsula of Paria; and the islands of Trinidad and Tobago, which are also, in part, mountainous. The shelf edge is indicated at the 100-fathom depth contour. The topographic features are of importance insofar as they influence vegetation and movement of sediments. Pollen transport and deposition is, of course, partly dependent on the location and altitude of source areas in relation to areas of deposition.

Climate

Every pollen grain and spore released by a flower or sporangium is transported for some distance through air before settling on a land or water surface. The principal climatic factors that determine the extent of this transport phase are wind strength and direction, and rainfall pattern.

According to Beard (1946), the prevailing winds on Trinidad are easterly, varying from northeast in the dry season to southeast in the rainy season. The average velocity at sea level in Port of Spain was 4 m.p.h., and the highest velocity recorded 25 m.p.h. Conditions are typically breezy. Probably this pattern also holds for the remaining part of the area under investigation. In any case, the coast lines lie under the general influence of the Northeast Trade Winds. Unfortunately, not much is known about the air circulation at higher altitudes, but it is unlikely that many pollen grains manage to reach these layers.

Rainfall also influences pollen distribution. The heavy, and often daily, tropical showers that are common in a large part of our area tend to wash the air clear of dust and pollen. Thus transport facilities are restricted.

An attempt was made on the first Gulf of Paria survey, from April to June, 1952, to sample the atmosphere for pollen. A vacuum-cleaner was rigged up on one of the mastheads of the survey vessel. The apparatus had been tested in Holland, where it worked efficiently, but the air samples obtained from the eastern Gulf of Paria failed to produce a single pollen grain. This may be a direct indication that airborne transport of pollen in our area is limited.

Noticeable quantities of airborne pollen can be expected only in the Gulf of Paria and on the northern Trinidad and Paria shelf, close to the shore lines. It appears extremely unlikely that airborne pollen reaches the shelf area east of Trinidad and east of the Orinoco delta.

Hydrography

When pollen settles upon a moving water surface it floats for some time and then slowly descends to the bottom. The actual speed of this process is difficult to measure directly, as it is influenced by many factors of unknown magnitude. The floating time depends further on the specific weight of a particular grain, the surface properties of the wall, and the speed with which the protoplasm decays. Settling in water is retarded by turbulence, especially in moving water masses. In addition, the slight density difference between fresh and salt water will have an influence. Finally, the strength of the local tidal currents is an important but hardly measurable factor.

Therefore, only the residual water movements will be described. In this respect we are fortunate in having at our disposal the results of the detailed hydrographic survey made in the area of investi-

gation by Postma (van Andel and Postma, 1954), and also in Koldewijn's study (1958).

The main features of the water circulation pattern are summarized in text-figure 2, and can be described as follows:

1) Orinoco River system: The drainage area is formed by the Llanos depression, which is bordered by the Cordillera de la Costa, the Andes, and the Guayana highlands. Pollen may thus be gathered from mountain and plains vegetation. Reworked pollen can be expected to be freed by the erosion of exposed Tertiary and Cretaceous strata in the Andean foothills. At Barrancas the Orinoco distributaries enter the delta plain and are divided into several branches. Residual current velocities decrease, and sedimentation of suspended material begins. In the lower delta there is a gradual transition to the tidal reaches of the estuaries.

The delta watercourses can be divided into the muddy Orinoco distributaries, through which the main Orinoco discharge is carried seaward, and the back-swamp rivers, which are recognizable by their clear "black" water. The latter drain excess rain-water from the peaty back-swamps. The delta is largely flooded in the rainy season, whereas in the dry season the water level falls, and the levees are exposed. The back-swamps remain waterlogged, however, for the greater part of the year. Pollen may be gathered by the moving Orinoco water masses at any stage during their journey through the delta, but at the same time, some pollen is already being deposited on the levees and in the back-swamps.

Erosion of sub-Recent delta deposits takes place in the meander belts of the tidal channels in the outer delta, especially in the eastern part. Considerable amounts of pollen that has been deposited earlier in a back-swamp area may therefore be liberated again and carried off seaward.

The net result of these processes is that the water masses discharged from the estuaries into the sea contain pollen of various origins in suspension. The pollen may have been derived directly from the coastal vegetation bordering the estuaries, or it may have had a shorter or longer history of air transport, water transport, or reworking in one or more cycles. Turbulence in the moving water masses, which is especially strong in the tidal region, will tend to mix the suspended pollen thoroughly. The degree of turbulence cannot be measured directly, but the effect can be judged by the degree of homogeneity with which sediment and pollen are deposited. In the back-swamp area, water movements are much

more restricted, and lateral transport of pollen in shallow water can presumably take place only during flood stages.

2) Northern llanos river system: The sediments of the northern part of the delta plain were not accumulated by the Orinoco River but by several smaller rivers, such as the Rio Grande, San Juan, and Guanipa, which descend from the Serrania del Interior and drain the northeastern part of the llanos. These rivers transport much less water and carry little sediment. They reach the sea in wide estuaries without bars and of simple morphology. As a pollen-gathering area they differ slightly from the main Orinoco estuaries.

3) Gulf of Paria and the open sea: When the river discharge from the estuaries comes into contact with moving marine water masses, the nature and direction of the water circulation pattern changes considerably. Marine water movement in this area is dominated by a strong westward current, which forms part of the Atlantic equatorial current system. The main features of water movement that are of especial interest here are summarized below, following the detailed descriptions given by Postma (1954):

a) The residual current pattern is shown in text-figure 2. Note here especially the eddy-like current present in the eastern part of the Gulf of Paria.

b) Estuarine circulation existing in the rainy season: Oceanic water enters the Gulf of Paria and the large eastern estuaries in subsurface layers, as far as the western Gulf, while the lighter, fresh river discharge flows seaward on top.

c) Existence of rather strong tidal currents, especially in the estuaries.

These data are invaluable for an understanding of the water-borne phase of pollen transport. In general, it appears possible for pollen escaping in suspension from the estuaries to be transported over large distances by marine currents. The estuarine circulation causes pollen that settles on the water surface in the estuaries to be transported seaward farther and in larger quantities than pollen that is already in suspension in the river water flowing through the delta.

Locally, marine currents may be so strong that active scour of the sea bottom takes place, as, for example, in the Serpent's Mouth. This phenomenon, together with wave erosion of exposed cliffs composed of soft Tertiary formations, such as those along the southwestern point of Trinidad, and erosion of shallow banks, indicates possible sources of reworked pollen and other microfossils.

Phytogeography

The demarcation of pollen source-areas is a prerequisite for full understanding of pollen dissemination patterns. For this purpose a botanical inventory of the terrestrial and floating vegetation of a large region surrounding and partly covering the area of deposition is necessary.

Unfortunately, only the floras of Trinidad and Tobago can be considered as being adequately known. Only scattered information is available from the Peninsula of Paria, the Orinoco delta, and the Venezuelan llanos. The author was able to make a short botanical reconnaissance in the Orinoco delta in January, 1956, and made first-hand observations on the distribution of plant communities and of palynologically important plant species. Reference is made to the detailed studies of Beard (1946, 1949) for Trinidad and Tobago, and some remarks on the plant communities encountered in the Orinoco delta, and their relations with the soil and water conditions governing their distribution, will be made here, as these large swampy areas form one of the main sources of pollen. The phytogeography of the remaining area is of lesser importance and will not be further discussed. The author was able to distinguish seven different vegetation types in the Orinoco delta, based on his own field observations, a study of aerial photographs, and a comparison with the literature (Beard, 1946; Lindeman, 1953). They are the following:

a) Mangrove forest: A very uniform vegetation type, virtually consisting of only two species, *Rhizophora mangle* and *Avicennia nitida*, in varying proportions. *Laguncularia racemosa* occurs locally. It forms belts along the coasts and for some distance upstream along the major tributaries, approximately to the point where the brackish tidal influence ceases. The typical soil of this vegetation type is a soft bluish-gray clay, strongly penetrated by a dense root felt. The absence of *Avicennia* in the strongly dissected southeastern part of the delta is striking. Picas B, D and F (see diagram 1) traverse this vegetation type.

b) Mixed swamp forest: A tall, mixed forest with a rather restricted number of dominant trees, among which *Symphonia globulifera*, *Pterocarpus officinalis*, *Bombax aquaticum* and the palms *Euterpe* sp. and *Manicaria sacchifera* could be recognized. It forms extensive forests in the lower delta, often directly behind the mangrove belt, especially in
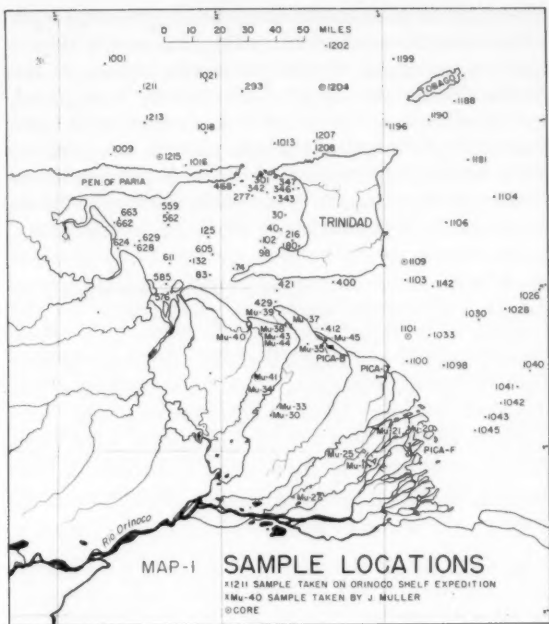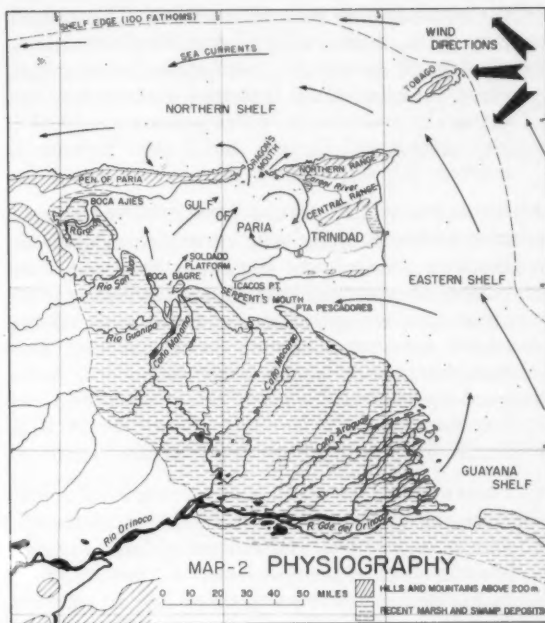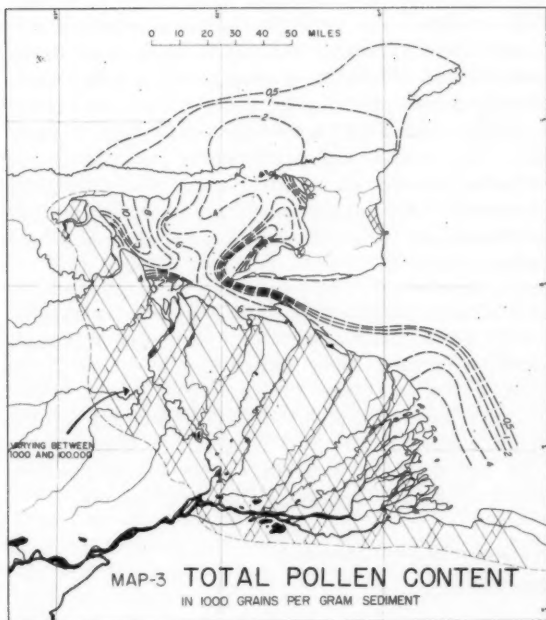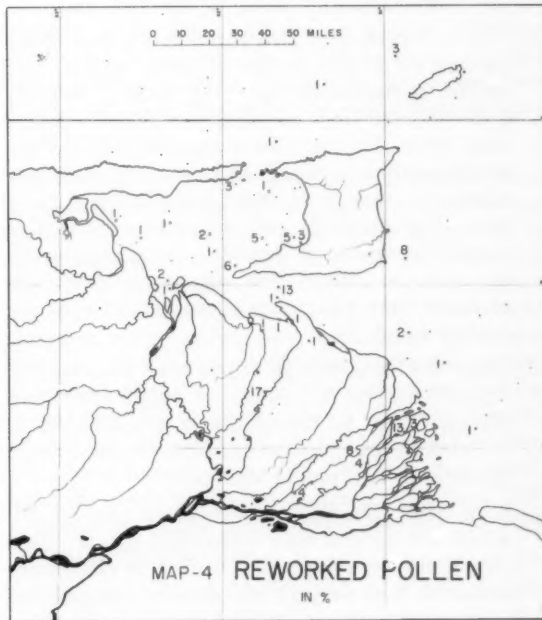
TEXT-FIGURE 1

TEXT-FIGURE 2

TEXT-FIGURE 3

TEXT-FIGURE 4

the southeastern part of the delta. The grayish clay soil is covered with a layer, 30–50 cm. thick, of very soft humic clay with abundant decaying plant material. Tidal influence is restricted, but seasonal variations in water level are probably also quite small. Picas E and F (see diagram 1) traverse this vegetation type.

c) Erythrina swamp forest: This is a rather open mixed forest type, with heavy undergrowth. *Erythrina glauca* is the dominant tree, but some palms (*Mauritia* and *Euterpe*) may also occur. This forest type is typical more of the upper delta, where seasonal variations in water level predominate, than of the lower delta, which lies more under the influence of tidal fluctuations and was found on the levees, traversed by Pica E. A stiff clay soil is present here (see diagram 1).

d) Palm swamp: An open, bush-like vegetation with emerging clusters of palms, mainly *Mauritia* sp., *Manicaria sacchifera*, and *Euterpe* sp. Heavy undergrowth and soft peaty soil deposits make this an exceptionally difficult vegetation type to traverse. Pica D penetrates into this type, and pure peat deposits are formed here (see diagram 1). The soil is permanently waterlogged, and fluctuations in water level, if any, are seasonal. It covers extensive areas in the central delta, locally known as "Morichales."

e) Herbaceous swamp: Low vegetation with strongly varying local dominance of ferns, sedges, low shrubs, *Montrichardia* sp., and, locally, floating grass. Stunted trees and scattered *Mauritia* palms may occur. The vegetation remains more or less permanently inundated, with only seasonal variations in water level. Peat deposits are formed here. Unfortunately, no penetration into this vegetation type was possible, and consequently no data on the pollen deposition could be gathered here. It covers great expanses in the central delta.

f) Dune and beach ridge vegetation: This type of vegetation, which consists of small trees and shrubs, occurs locally on sandy beach ridges in the coastal area, but is believed to be of little importance as a pollen source.

g) Rain forest: The higher levees in the upper delta, which are flooded only seasonally, at very high river level, were originally covered by rain forest, which is now largely cleared for agricultural purposes. Remnants of this forest are still visible here and there in the shape of very large trees with a dome-like crown emerging above a several-storied forest.

The horizontal distribution of these vegetation types follows certain ecological rules. This makes it possible to recognize several landscape regions in the delta. Firstly, the upper delta can be recognized, where seasonal fluctuations in water level predominate and well developed levees are present. The original vegetation of these levees was rain forest. Depending on the water level, the back-swamp area is covered with *Erythrina* swamp forest, palm swamp, or herbaceous swamp, or open water is present where drainage is blocked by high levees. Levee building is much less pronounced in the central delta, and although the caños here show distinct tidal fluctuations, the latter do not penetrate far into the back-swamps. This is the domain of the *Erythrina* swamp forest, palm swamp, and herbaceous swamp, and it is probable that these vegetation types here represent a serial succession, controlled by the decreasing supply of mineral sediment.

The outer delta, where the influence of tidal fluctuations is strongly felt and where an adequate supply of mineral sediment is present, is characterized by the dominance of mixed swamp forest in the inner belt and of mangrove forest in the outermost belt. The southeastern part of the outer delta is strongly dissected by a network of meandering tidal channels, and differs in this respect from the central sector, where a few large, straight Orinoco branches traverse a very extensive but largely undrained back-swamp area. The former area is covered by mixed swamp forest, growing on a clayey soil, the latter by palm swamp and herbaceous swamp on a peaty soil. The coast of the southeastern part also has a different character, as indicated by the absence of *Avicennia*, which is common along the northern and northwestern delta shores, where mud-flats are more extensive.

All of these variations in delta vegetation and sediments are of direct interest in a palynological study, mainly because they indicate the locations of potential source areas for important pollen types. In the separate discussion of the distribution of these types, further details will be given on this subject. The approximate location of the source areas is given in the accompanying maps and graphs.

DISTRIBUTION OF MICROFOSSILS
Introduction

In this section the distribution of the principal microfossil types will be discussed, with the aid of a number of maps and graphs. The complete documentation is given in the distribution chart (Table 1).

The surface data will be discussed first (text-figs. 3–23). The microfossil content of the samples taken in the delta picas is given in a separate chart (diagram 1), because the details could not possibly be shown to scale on the other maps. Next, the variations in the microfossil content of the cores will be considered (diagram 2), and finally some data on sub-Recent or Pleistocene samples will be given.

Surface samples

1) *Total pollen content:*

Text-figure 3 shows the variations in total pollen content of the samples examined. On this map the land areas that are not cross-hatched represent outcropping Pleistocene or older sediments. On the eastern shelf, stations 1026 and 1181 also show older sediments exposed on the sea floor.

In the delta the pollen content of scattered samples is indicated. They show a high but variable pollen content. The nature of this variation can be studied better in the chart (diagram 1), where the total pollen content of the surface samples from the picas is given.

The location of these four picas is shown in text-figure 1. The topography is indicated on an ex-aggerated vertical scale. Pronounced natural levees are found along Caño Sacupano (Pica E) and Caños Jefe-Cubaca and Guayo (Pica F). In these two picas the average mineral content of the samples is also highest. These levees have an elevation of not more than 1 meter above mean tide level, and their deposits have a low organic content. Picas D and B are situated in areas where less mineral sediment penetrates. Levees are therefore less pronounced here. In the back-swamp areas, peat formations are found that are practically free of mineral admixture. In Pica E the total pollen content fluctuates rather strongly but reaches a minimum in the levee deposits, where slightly coarser mineral sediments were laid down.

The local presence of prolific pollen producers such as *Terminalia* and *Rhizophora* further influences the total pollen content, because high percentages of these types go together with peaks in total pollen content. In Pica F the total pollen content is also lowest in the levee deposits. Pica D penetrates far into a peat area, and here the total pollen contents are lowest on the levee, because of the relatively high mineral content. In the peat deposits they are also rather low, but this is due to the large amount of organic accumulation here. Pica B shows similar relationships between total pollen content and content of organic matter.

In general, it can be concluded that the total pollen content of the delta samples is at its maximum where both mineral supply and organic accumulation are at their minima, which is in sediments containing 20–50 per cent organic matter. It varies further in relation to the local presence of prolific pollen producers.

It would not be possible, even if the samples were available, to show this variation in pollen content on the large-scale map of text-figure 3. The pollen content is therefore shown only as a cross-hatched pattern, which indicates a range of variation between 1000 grains/gram on natural levees and the maximum of 100,000 grains/gram in back-swamp deposits. The landward boundary of this cross-hatched area represents the limit of Holocene swamp deposition. Outside of this limit no Recent pollen is preserved.

The sediments that accumulate in open water offshore are much more evenly sampled, and show a different, but also quite regular, variation in pollen content. It was possible here to construct lines of equal pollen content ("isopollens") at intervals of 1000 grains/gram (text-fig. 3). The overall picture thus obtained shows, first of all, a consistent decrease seaward, with the heaviest pollen concentrations opposite the larger Orinoco distributaries. This seaward decrease is most clearly visible off the eastern delta. Here, at first, a gradual decrease down to 3000 grains/gram is visible. Then a rather steep decline to 500 grains/gram is shown, and farther seaward, the pollen contents remain more or less constant.

Considering the predominant easterly wind, it must be concluded that practically all of the pollen contained in the sediments of this area is derived by water transport from the large eastern estuaries. This is further confirmed by the fact that the highest concentrations are in front of the Rio Grande – Caño Araguao group of estuaries, whereas farther along the coast in a north–northwesterly direction, where large estuaries are absent, the pollen contents decrease until the Caño Macareo is reached. It is also clear that the strong Equatorial Current deflects the pollen-bearing estuarine discharge in a north-westerly direction, the pronounced drop from 3000 grains/gram to 500 grains/gram marking the zone of maximum deflection.

Settling of the suspended pollen and coarser sedimentary particles reaches a maximum opposite the estuaries because of decreasing current velocities. However, not all of the pollen settles on the outer shelf, because appreciable quantities are still found

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here. Some of these pollen grains are derived, of course, from the Guayana shelf, following the current direction.

Approaching the Serpent's Mouth channel from the southeast, close to the delta coastline, very low pollen contents are observed, because of the absence of large estuarine outlets. The wind directions here still impede direct airborne transport of delta pollen seaward. However, along the southern coast of Trinidad, evidence of a slight increase in pollen content is seen, and this increase must be due to an airborne supply from Trinidad with northeasterly winds, as the rocky coast here, without major rivers or swamps, does not favour water transport of pollen from the island into the sea.

Near the narrowest portion of the Serpent's Mouth channel, a new supply of pollen becomes evident in the concentration opposite the Caño Macareo estuary. The Macareo discharge, which is rich in pollen, is carried with the westward-flowing marine current alongside of oceanic waters with a low pollen content. Evidently very little mixing occurs, which results in a very steep decline in the pollen content of bottom sediments between Punta Pescadores and the southwestern point of Trinidad. The same pattern is visible on Postma's map of the concentration of suspended matter at the surface (van Andel, Postma and Kruit, 1954, text-fig. 23) and the distribution of Secchi disc visibility (ibid., tex-fig. 25) during the early rainy season, which confirms the idea that the pollen distribution mainly reflects waterborne transport.

The effect of the entrance of oceanic water, which is poor in pollen, through the Serpent's Mouth channel into the Gulf of Paria alongside of water that is rich in pollen derived from the Caño Macareo remains visible in the pollen content of the bottom sediments in the Eastern Gulf as an elongated patch of low pollen contents, which is bordered by the isopollen line of 3000 grains/gram. This is accentuated by the existence of the eddy-like current here. Toward the Trinidad coast, the sediments again show an increase in pollen content, which is most probably due to airborne supply from Trinidad. Opposite the mouth of the Caroni, which is the largest river on Trinidad, a very pronounced concentration of pollen is visible, which is probably caused by pollen that is produced locally in the small Caroni delta and carried seaward with the river discharge.

The pollen distribution in the Eastern Gulf shows a different pattern. In the large funnel-shaped Boca Vagre estuary, low pollen contents are shown, which increase seaward rather rapidly only to show, farther

to the northeast, the normal gradual decrease which is also found opposite the other Orinoco estuaries. This anomaly is caused by the coarse-grained material that is being deposited in the Boca Vagre by the Caño Manamo, while the sedimentation of the finer fractions, together with the pollen grains, finds its maximum somewhat farther offshore in quieter waters. It should be recalled here that the bottom sediments of all the large Orinoco distributaries consist largely of rather coarse sand, which does not contain any pollen grains at all. The track of the Boca Vagre discharge is indicated farther along in the Central Gulf by the northeasterly-trending tongue of higher pollen concentrations near the Dragon's Mouth.

Still farther westward along the delta front, in the Rio San Juan estuary and in the Boca Ajies, far higher pollen concentrations are found than in the Boca Vagre. It has already been mentioned that these rivers carry very little sediment. This factor, together with the narrowing shape of the Gulf here, which increases the number of wind-transported pollen grains caught per unit of water surface as compared with the Central Gulf, easily explains these very high pollen concentrations.

In the area of the Dragon's Mouth the isopollen lines show clearly the discharge of Gulf water, which is rich in pollen, into the ocean, in which the pollen content of the bottom sediments is lower. There is, however, one slight anomaly in the Northern Gulf, where a tongue of sediments poor in pollen is noticeable near the southern Paria coast. This very probably reflects the entrance of an undercurrent of ocean water into the Gulf through the Dragon's Mouth, the existence of which has been determined hydrographically by Postma (van Andel, Postma and Kruit, 1954). This ocean water is poor in pollen and dilutes the pollen-rich Gulf water, as a consequence of which the bottom sediments also show a lower pollen content.

From the Dragon's Mouth westward, the westerly deflection of the Gulf discharge along the northern Paria coast is indicated by the 1000 and 500 isopollen lines. In the northwesternmost corner of the shelf, where the lowest pollen contents occur, the supply has become almost negligible.

Northeastward from the Dragon's Mouth, a concentration of pollen can be observed north of Trinidad and west of Tobago, whereas farther eastward, south of Tobago, a decrease is visible. This pattern indicates a noticeable supply of primarily airborne pollen from Trinidad and Tobago. Also, there is probably some supply of pollen derived

from the eastern Orinoco delta and carried in suspension over the shallow area of non-deposition present east of Trinidad. The bottom sediments of this area consist mainly of coarser-grained material and calcarenites, and Pleistocene deposits occur locally at or near the surface, which makes them rather unsuitable for palynological study. The few Recent samples examined from the eastern shelf, however, have the low pollen content typical of outer shelf sediments.

The main conclusions are:

1) The Orinoco delta has been the source area for most of the pollen contained in the offshore sediments. This can be deduced from the distinct decrease in pollen content from the estuaries seaward.

2) Marine currents are the main medium of transport. This is shown by the correspondence between the pattern of decrease in pollen content with the current and the sediment-transport pattern.

3) The effect of wind transport is small and is noticeable only in pollen concentrations to leeward of Trinidad and Tobago. This is corroborated by the negative results of air sampling in the eastern Gulf of Paria.

The total pollen content is further influenced by the following factors: 1) Distance from source; 2) rate of sedimentation; 3) coarseness of sediments; and 4) presence of carbonates and organic matter.

From a palynological point of view it would be interesting if the total pollen content of the sediments could be converted into the amount of pollen deposited on a given surface (1 cm^2.) in a given length of time (one year). In this way the so-called "absolute pollen frequency" could be obtained. The surface data alone do not permit this, however mainly because the sedimentation rate is too imperfectly known. It appears that no simple relationship exists between van Andel's figures for the rate of deposition during the last 700 years and the total pollen content at the surface. In the Western Gulf, low values of 30 cm. per century coincide with very high pollen contents because of the proximity of the pollen source area. In the Boca Vagre, a high rate of 100 cm. per century produces a low total pollen content; and along the southwestern coast of Trinidad, low rates of 12–20 cm. per century are associated with low pollen contents due to the small supply of pollen. Assuming constant conditions during the last 700 years, it is possible to derive from these figures an estimate of the absolute pollen frequency expressed in grains/cm^2./year. The values

obtained would vary from 3600 in the Western Gulf, to 2400 in the Boca Vagre, and 168 in the Eastern Gulf (assuming an average water content of the fresh sediment of 60 percent (van Andel), and a specific weight of the clay material of 2.0).

It is, of course, also possible to calculate the total pollen content using the clay fraction of the sediments only. In this way a more regular decrease in total pollen content seaward would be obtained. However, the straightforward determination of total pollen content per gram of dry sediment was preferred, because this is virtually the only way in which this value can be determined in older, indurated sediments, in which clay content and rate of sedimentation are usually difficult to measure.

2) *Percentage distribution of pollen:*

The frequency with which each type occurs has been calculated in percentages, and these values have been plotted separately on distribution maps and the source areas determined as accurately as possible. It then appeared possible to recognize various groups of types on the basis of similarities in their distribution patterns. From each group, one or more examples will be discussed in detail below.

REWORKED POLLEN

First of all, it appeared necessary to separate reworked older pollen from Recent grains. Tertiary pollen reworked by the Orinoco headwaters in the Andean foothills and deposited in the recent Orinoco sediments is rather easily distinguishable from Recent pollen by its flattened shape and poor preservation. It is often corroded and stains differently. Pleistocene pollen is more difficult to recognize as such on the basis of preservation, and the separation of reworked older Holocene pollen from Recent pollen is next to impossible.

In text-figure 4 the distribution of obviously reworked grains is plotted as a percentage of total pollen content. This map shows that reworked grains are concentrated in certain areas. In the first place, they are rather abundant in the levee deposits in the delta, where values up to 17 per cent may occur. These grains have evidently been eroded and redeposited by the Orinoco river system. In the outer delta and in the offshore zone near the delta front, the percentage of reworked pollen drops because the supply of locally produced Recent pollen outnumbers the reworked material.

Near Trinidad a second source of reworked grains is visible. The high percentages in the Gulf of Paria around the southwestern point of Trinidad are evidently related to the Tertiary sediments, which are locally eroded by wave abrasion on shoals and cliffs and which also yield fossil foraminifera and Radiolaria (see Kruit, in van Andel, Postma, and Kruit, 1954, text-fig. 60). South of Trinidad, in the Serpent's Mouth channel, reworked

material also occurs. The reworked grains found east and north of Trinidad on the shelf have probably been derived from eroded Pleistocene deposits. They may have been originally Pleistocene in age, or may have been reworked at that time from the Tertiary.

In the following paragraphs, the reworked pollen has not been included in the pollen total on which the percentages of the Recent pollen types have been calculated, as their occurrence bears no relation to Recent plant distribution and pollen dissemination, and their inclusion would only tend to obscure the Recent distribution patterns.

Mauritia sp. (PALMAE)
Plate 1, figure 1

The typical echinate, monocolpate pollen of *Mauritia* cannot easily be mistaken. The peculiar foundation of the short, rounded spines, and the nearly spherical shape, are distinct characteristics. The grains are medium heavy.

Mauritia is very common in large expanses of swamp and marsh vegetation in the central and western Orinoco delta. It occurs in varying abundance from scattered occurrences to dense stands, the so-called "Morichales." It is largely absent in the brackish-water belt along the delta front, nor does it occur in the closed mixed swamp forest found in the eastern delta. It also occurs locally on Trinidad in the swamp and marsh environments (Beard, 1956). In the Venezuelan llanos it is especially common along the river courses. In text-figure 5 the occurrence is indicated by cross-hatching. The relative abundance could not be mapped accurately.

The distribution of *Mauritia* pollen as shown in text-figure 5 and diagram 1 shows, in general, strongly fluctuating percentages in the central delta. These percentages vary in direct proportion to the local abundance of the mother plant. In the mixed swamp forest of the eastern delta, *Mauritia* is not abundant, and here the percentages are low, as shown most clearly in Picas E and F. In Pica D, however, the peat area is covered by a Morichal vegetation, and this is reflected in the relatively high pollen percentages here. In Pica B, a high *Mauritia* percentage in one peat sample indicates the abundance of the *Mauritia* palm. It is evident from these data that atmospheric mixing is unable to equalize this locally strongly variable pollen production to any appreciable degree.

Offshore, where lower but more regularly distributed percentages are found, concentrations are visible in the Gulf of Paria and, less clearly, in a small area opposite the eastern delta. Apparently the western estuaries, which traverse the areas where *Mauritia* is most abundant, carry a proportionally larger amount of *Mauritia* pollen into the Gulf than is possible for the eastern estuaries. Most of these grains apparently settle in the Gulf, and very few escape through the Dragon's Mouth to the northern shelf.

Avicennia nitida Jacq. (VERBENACEAE)
Plate 1, figure 2

The tricolporate *Avicennia* pollen is easily recognized by its reticulate sculpture, rather thick wall, subprolate form, and medium size. The mother plant forms one of the main constituents of the mangrove forest. The areal distribution is indicated in text-figure 6, and is restricted to the outer brackish-water belt of the delta, but the species penetrates inland along the river courses as far as the brackish influence is felt. Its almost complete absence in the strongly dissected eastern delta is remarkable, although it is abundant along the straight northern and northwestern delta edge. *Avicennia* has not been observed in the outermost vegetation belt, but generally occupies the inner parts of the mangrove forest. It also occurs locally in the Trinidad swamps.

The general distribution in the delta shows that in the eastern delta, where *Avicennia* is scarce, no pollen was found. In the central delta, *Avicennia* pollen is frequent in the source area, but apparently only very few grains are carried inland by wind transport.

In Picas E, F, and D, *Avicennia* is also virtually absent. Noticeable percentages are reached only in Pica B, where *Avicennia* is about equally as abundant as *Rhizophora*. Nevertheless, the highest percentages of *Avicennia* pollen in the delta are much lower than those reached by *Rhizophora*, which indicates that *Avicennia* is comparatively under-represented in relation to the abundance of the mother plant in the vegetation, which equals that of *Rhizophora*.

Offshore, an area with a higher average percentage can be separated from one with a lower average. The area with higher percentages, restricted to the western Gulf of Paria, is closest to the main source area. In the eastern part of the Gulf and on the northern shelf, values are low, and apparently the rather heavy *Avicennia* pollen is not carried over great distances in suspension but settles comparatively soon. The pollen distribution is closely related to the source area, and water appears to have been the main medium of transport.

Rhizophora mangle L. (RHIZOPHORACEAE)
Plate 1, figures 3, 3a

Rhizophora pollen is, in general, fairly easy to recognize, although rather strong variation in size and in the appearance of pores has been observed, which is probably due to differences in preservation. The pollen is small, spherical, nearly psilate, and the most typical characteristics are the equatorially elongated pores, which are combined with three rather weakly pronounced colpi.

Rhizophora is the second main mangrove species, and generally forms the outer vegetation belt along the delta front and, together with *Avicennia*, penetrates some distance inland along the estuaries. The width of the *Rhizophora* belt varies with the amount of mud accumulation. In the eastern delta, the belt is never very broad
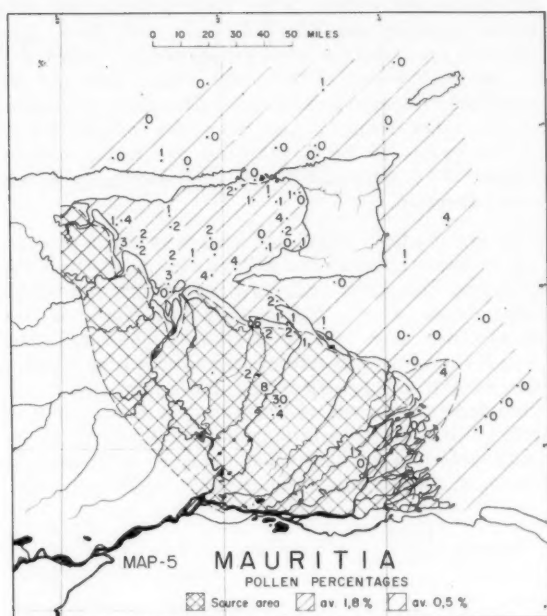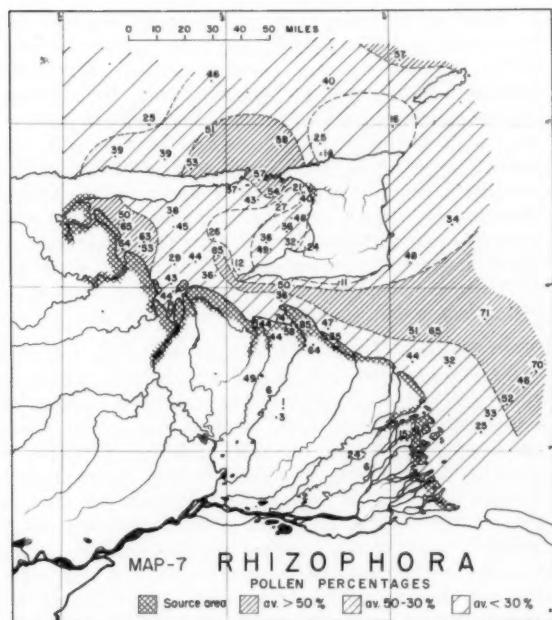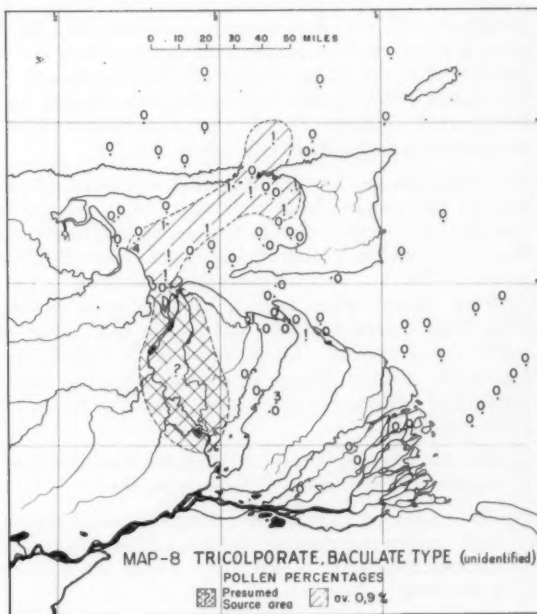
TEXT-FIGURE 5

TEXT-FIGURE 6

TEXT-FIGURE 7

TEXT-FIGURE 8

or continuous because of the numerous meandering estuary branches, where strong tidal currents are eroding concave banks, and mud accumulates only on convex banks, where point-bar deposits are laid down. On these point bars, *Rhizophora* grows in dense stands, whereas the back-swamp vegetation is exposed on the eroded banks. On the shores of the Gulf of Paria, the situation is different; the coastal mud-flats are more extensive, and the *Rhizophora* belt is more continuous and wider. The species occurs locally in Trinidad in the small swamps on the western shore (Beard, 1946). The approximate distribution of the *Rhizophora* belt is indicated in text-figure 7.

The map of pollen distribution (text-fig. 7) shows low values in the central delta and high values within the source area. In Pica E (diagram 1), which is situated at the upstream limit of the *Rhizophora* vegetation, the pollen is still regularly present but in low percentages. Apparently these grains are windblown from the outer vegetation belt. In Pica F, a well developed *Rhizophora* belt 30–40 meters in width is found on the weakly defined levees, and *Rhizophora* pollen is dominant in the samples there.

In relation to the occurrence of the mother plant, *Rhizophora* pollen is heavily over-represented in the pollen total. In Pica D, the *Rhizophora* belt is clearly expressed in the pollen percentages, but it appears that the wind has distributed the pollen in low quantities over the entire back-swamp area. Pica B traverses a well developed *Rhizophora* belt, and accordingly, percentages of *Rhizophora* pollen are very high. This distribution in the delta samples indicates that *Rhizophora* is a very prolific pollen-producer, and it is due to this fact that the pollen grains are found regularly in the central delta outside the source area, having been transported through the air by the predominantly northeasterly to southeasterly winds.

Rhizophora can be classified as a wind pollinated species, and in this respect it is well adapted to its special environment, where, due to the strong sea breeze, its flowers are seldom visited by insects, as observed by the author. Offshore, a rather complicated-looking pattern appears, characterized mainly by a number of areas with higher concentration alternating with areas of lower concentration. These areas with higher concentration are not always in contact with the source area. The key to this anomalous situation lies in the following facts:

1) *Rhizophora* pollen is very small, and is therefore easily transported over a large distance by wind.

2) The exposed location of the *Rhizophora* belt and the high pollen production favour offshore transport because *Rhizophora* pollen is the last to settle on the outflowing surface water.

These facts, in combination with wind directions and current pattern, offer a logical explanation for the offshore percentage distribution pattern. The author's hypothesis is set forth below:

In the western corner of the Gulf of Paria, the high values opposite the Rio San Juan and Boca Ajies estuaries are caused by a low supply of other pollen, due to the small extent of the inner swamp belt and the restricted drainage. The extensive *Rhizophora* vegetation, on the other hand, is very favorably located for its pollen grains to be trapped on the water surface, because the estuaries are at right angles to the prevailing wind direction.

Opposite the Boca Vagre, the *Rhizophora* pollen percentage is lower because the large discharge of the Caño Manamo has been collecting pollen from a much larger area. There, *Rhizophora* pollen does not outnumber the other types so markedly. The same holds true for the Macareo estuary and for the area opposite the eastern delta, where *Rhizophora* also grows less abundantly. Seaward from the eastern delta, a distinct and gradual increase in percentage is observed. In the table below, these figures are analyzed in relation to distance offshore and total pollen content per gram:

Sample number	Distance offshore (in miles)	*Rhizophora* (%)	Total pollen/g.	Total *Rhizophora*/g.
1045	20	25	3827	958
1043	30	33	3033	1011
1042	38	52	383	199
1041	47	46	271	225
1040	55	70	294	206

It must be remarked that the distance offshore has been measured in a straight line following the traverse of the samples, whereas it should actually have been measured following the current pattern. In addition, the pollen content of samples 1041 and 1040, in particular, has probably been largely derived from the Guayana shore. Nevertheless, the same trend is visible in the samples taken somewhat farther north. These figures demonstrate clearly that the *Rhizophora* percentage is inversely proportionate to the total pollen content. If the *Rhizophora* content per gram is calculated, a normal decrease is found due to the progressive settling of *Rhizophora* pollen.

The offshore increase of *Rhizophora* observed in this area is therefore relative only, and is probably due mainly to the relatively small size of the *Rhizophora* pollen in comparison with the bulk of the other pollen types discharged from the estuaries. *Rhizophora* pollen is settling farthest seaward and is thus increasing in percentage. This is thought to be a distinct case of progressive sorting of pollen grains, resulting in a relative quantitative increase in the smallest grains seaward. The increase is augmented by estuarine circulation, because *Rhizophora* also happens to occupy the outermost vegetation belt and is thus more easily transported in the seaward-flowing upper water layers.

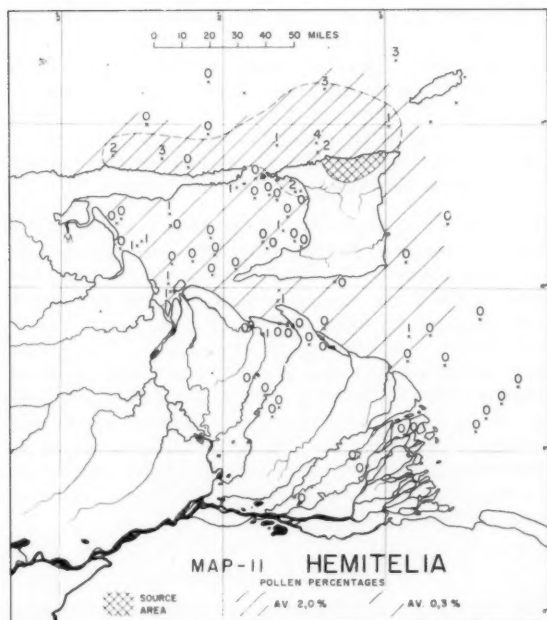On the basis of these results, obtained in an area where transport must have taken place almost exclusively by
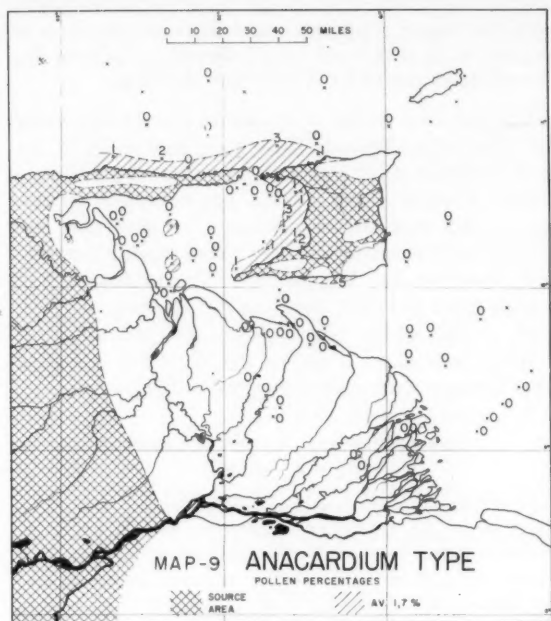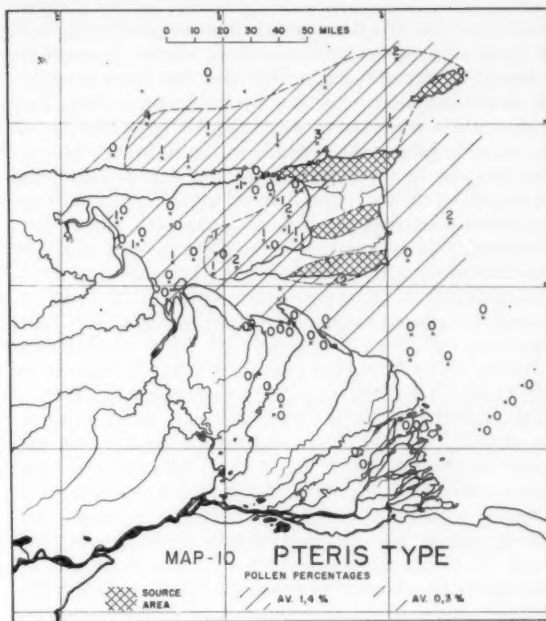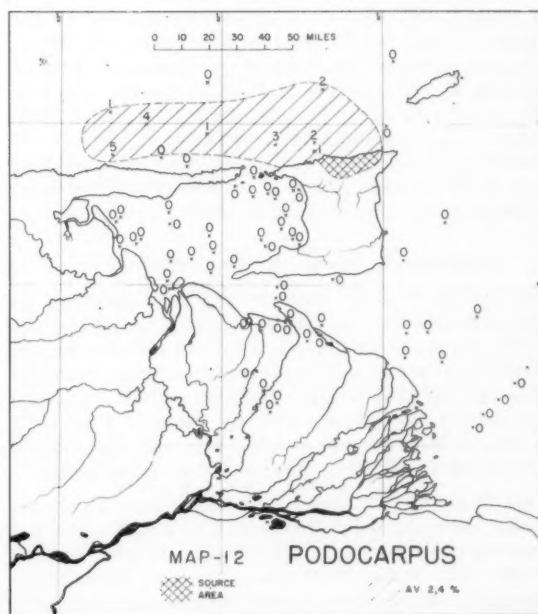
TEXT-FIGURE 9

TEXT-FIGURE 10

TEXT-FIGURE 11

TEXT-FIGURE 12

water, it is now possible to proceed to the further analysis of the *Rhizophora* pollen percentages in the Gulf of Paria and on the northern shelf, where the possible presence of windblown pollen and the more complicated marine current pattern are confusing factors. The continuation of the patch with high *Rhizophora* values on the outer shelf is clearly visible in the Serpent's Mouth and can also be seen penetrating into the Gulf of Paria up to a short distance past Icacos Point. Then, following the marine current pattern, an area with rather low *Rhizophora* values is found in the eastern Gulf, more or less coinciding with a patch of low total pollen content. The decrease in *Rhizophora* percentages here may be caused by a large supply of other types from the Caño Macareo and Boca Vagre and by wind supply from Trinidad. The *Rhizophora* percentages again increase in the Dragon's Mouth and on the northern shelf, in a pattern similar to that shown by the total pollen content. As virtually no *Rhizophora* vegetation exists along the rocky northern shore of Paria and Trinidad, the only explanation for this increase in *Rhizophora* percentages is selective sorting in the northward-moving suspended pollen, which has its main supply from the western delta. If distance between main source and zone of maximum *Rhizophora* deposition is estimated, taking into account marine-current velocity and direction, values are obtained that are similar to those of the area opposite the eastern delta.

Both on the eastern and northern shelves, *Rhizophora* percentages again show a tendency to decrease away from the source of delta supply. This indicates a supply of other pollen types from other sources, and on the northern shelf it is probable that windblown pollen from Trinidad, Tobago, and the Paria peninsula tend to decrease the percentages of *Rhizophora* grains reaching the outer shelf area. For the eastern Trinidad shelf, however, this explanation is unlikely, in view of the prevailing northeasterly to southeasterly winds, and here it is probable that a supply of reworked Pleistocene pollen may have lowered the *Rhizophora* percentages.

Tricolporate, baculate type (unidentified)

This pollen type is characterized principally by its spherical form and baculate sculpture. It resembles *Ilex* pollen, but at present no certain determination can be given. Because the mother plant is uncertain, the source area can only be inferred indirectly from the pollen distribution (as happens only too often in fossil sediments). As shown in text-figure 8, this type occurs in the central delta and less frequently in the eastern delta.

This distribution, together with the remarkable distribution offshore, which is restricted to a narrow tongue traversing the central Gulf of Paria, starting in the Boca Vagre and ending with branches just outside the Dragon's Mouth and in the eastern Gulf, strongly suggests that this type of pollen is exclusively discharged by the Boca Vagre estuary. Its distribution in the Gulf sediments then indicates the stream along which the main water-mass leaving the Boca Vagre is moving

through the Gulf. This stream more or less coincides with the tongue of higher total pollen content shown in text-figure 3, which was also believed to indicate the travelling stream of the Boca Vagre discharge.

The preceding pollen types can be grouped together as delta-pollen because their main source lies in the vast swamps and marshes covering the Orinoco delta. Various other pollen types belong to this group but will not be discussed because they are found less frequently and their distribution patterns are therefore less informative. The next group of pollen types that will be discussed are those of Trinidad, under which heading are grouped all types having their main origin on the islands of Trinidad and Tobago and on the peninsula of Paria.

Anacardium type (ANACARDIACEAE)
Plate 1, figure 4

The typical striate-rugulate, tricolporate *Anacardium* type of pollen is rather distinctive and is probably derived mainly from the genus *Anacardium*. The two most important species represented in our area are *Anacardium occidentale*, a fruit tree commonly planted in all cultivated areas outside the swamps and also occurring spontaneously in the llanos, and *Anacardium excelsum*, a large dryland forest tree, which may occur locally.
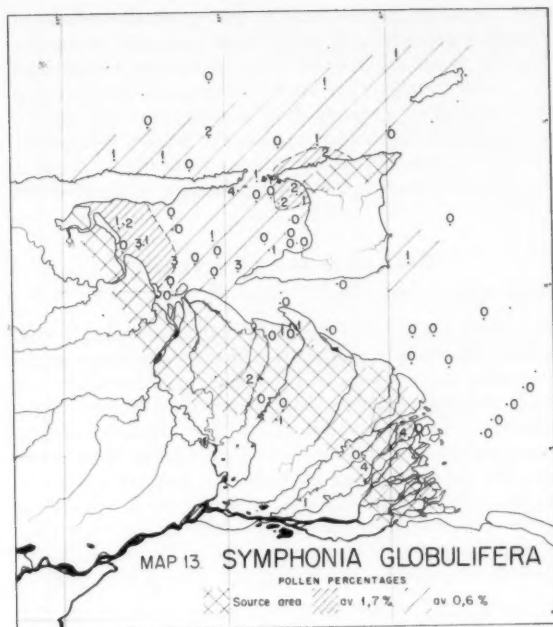
Some other members of the Anacardiaceae, such as *Spondias*, which have similar pollen, may also be represented. In general, however, Anacardiaceae do not occur in the swamps and marshes. Lindeman (1953) mentions only *Spondias mombin* occurring on beach ridges on the Guayana coast. Accordingly, the *Anacardium* type of pollen was found only once in a levee deposit in the delta, and this single grain may easily have been derived from the cultivated levees in the upper delta or from the llanos area farther upstream.

In text-figure 9, a distinct concentration is shown in the offshore bottom sediments along the southwestern and northern coasts of Trinidad and along the northern coast of the Paria peninsula. This distribution pattern differs completely from those of the delta pollen, and it is evidently controlled by wind transport. The grains must have been subjected to some water transport while settling to the sea bottom, but the *Anacardium* type may be considered as exhibiting a typically windblown pattern of distribution. The scattered occurrences of *Anacardium* pollen north of Boca Vagre can be attributed to transport via the Caño Manamo from cultivated areas upstream.

Pteris type (cf. PTERIDACEAE)

This type-group comprises all trilete spores that possess a distinct, smooth equatorial flange, a heavily verrucate-rugulate or reticulate sculpture on the distal side, and a smooth or nearly smooth sculpture on the proximal side. Their size falls generally between 40 and 50μ. These

TEXT-FIGURE 13

MAP 13. SYMPHONIA GLOBULIFERA
POLLEN PERCENTAGES
Source area   av. 1,7 %   av 0,6 %

MAP 14. TERMINALIA TYPE
POLLEN PERCENTAGES
Source area   av 7,3 %

TEXT-FIGURE 14

MAP 15. GRAMINEAE
POLLEN PERCENTAGES
Source area   av. 1,7 %

TEXT-FIGURE 15

MAP 16. COMPOSITAE
POLLEN PERCENTAGES
Source area   av. 0,7 %
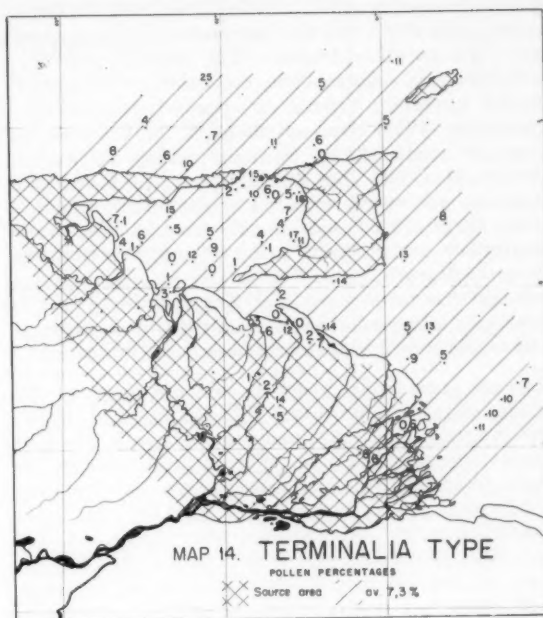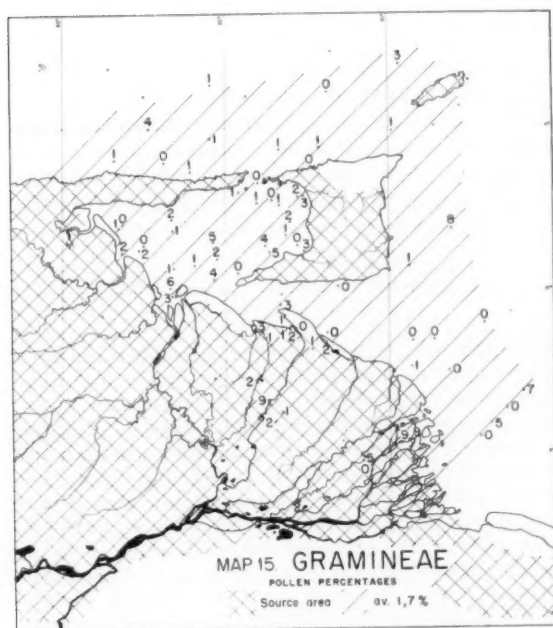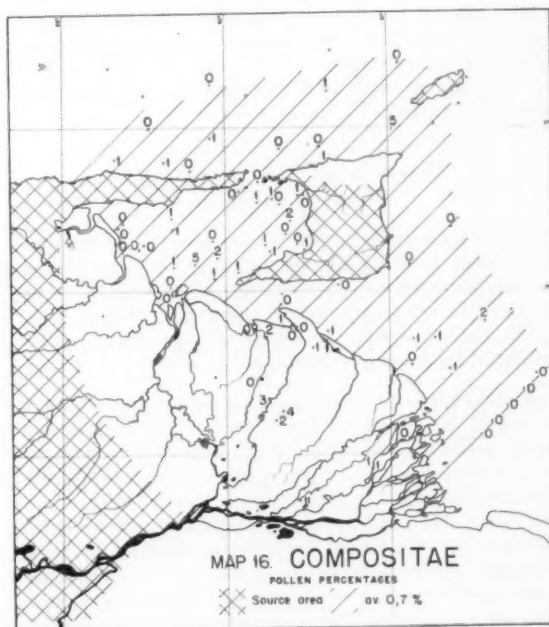
TEXT-FIGURE 16

spores are most probably derived from ferns belonging to the genus *Pteris*, but they may occur in other genera and even in other families. The author's reference collection was unfortunately not extensive enough to furnish a certain generic or specific determination. Lindeman (1953) does not mention the genus in his extensive study of the Surinam swamp vegetation. Posthumus (1928) lists several species of *Pteris* from Surinam, but mostly from the upstream mountainous areas. Beard (1946) unfortunately gives no data on the distribution of the genus *Pteris*, except one reference to *Pteris multiserialis*, which is a tree-fern growing in montane rain forest above 2500 feet altitude. In view of this scanty information and the uncertainties in determination, the source area cannot be accurately defined.

It seems improbable, however, that the spores of this group were derived from the swamp and marsh environment. Their most likely source area is the hilly-montane forests of Trinidad, Tobago, and, possibly, the Paria peninsula. This is clearly confirmed by the spore distribution shown in text-figure 10. Only one grain was found in the delta deposits, whereas offshore they are distinctly concentrated in the eastern Gulf of Paria, north of the Paria peninsula and north of Trinidad. This again is a predominantly windblown pattern of distribution. In comparison with *Anacardium*, *Pteris* has a wider distribution. This may be due to a difference in the source areas; that of *Pteris* probably lies at a higher altitude than that of *Anacardium*, thus giving the *Pteris* spores a better chance of reaching higher atmospheric levels because of the strong upward movement of air masses, especially on the mountain slopes, and consequently longer transport. It may also be partly caused by *Pteris* spores being liberated more abundantly than *Anacardium* pollen.

Hemitelia sp. (CYATHEACEAE)
Plate 1, figure 5

Hemitelia spores are easily recognizable by their perforated outer layer. These perforations are generally three in number and are situated in the equatorial zone between the arms of the trilete scar (see Erdtman, 1943, pl. 27 figs. 450–451). This type of spore may also be produced by other genera of Cyatheaceae.

Unfortunaley, the source area of these typical spores cannot be accurately defined. Beard (1946) does not mention *Hemitelia* from Trinidad, but, as his attention was mainly focussed on the tree vegetation, it is possible that his information was not complete as far as ferns are concerned. He does mention *Hemitelia grandifolia* from the montane rain forest of the Lesser Antilles north of Trinidad (Beard, 1949); the genus, or a related one, could therefore well be expected on Trinidad. This is at least strongly suggested by the spore distribution pattern shown in text-figure 11, which shows *Hemitelia* spores as absent in the delta and opposite the eastern delta. Southwest and north of Trinidad and north of Paria, they are found scattered over a rather wide area, but

with concentrations close to the northern coasts of Trinidad and Paria. It seems most probable, therefore, that the spores are derived from the northern range and that wind transport has been dominant in determining the distribution pattern. It is possible that the faintly indicated concentration opposite the Boca Vagre points to water transport via the Orinoco from the Andes and the coastal range, as *Hemitelia* is known to occur there locally.

Podocarpus sp. (CONIFERAE)
Plate 1, figur 6

The saccate grains of *Podocarpus* are unmistakable and cannot be confused with the pollen of any other plant occurring in the area of investigation. *Podocarpus* can safely be assumed to be absent from the Orinoco delta, although Beard mentions localized occurrences in marsh forest on alluvial terraces in Trinidad. He further classifies the occurrence of *Podocarpus* as follows: "Very scarce in evergreen seasonal forest, regularly present in lower montane forest, and abundant in montane rain forest." Its present-day source area is therefore almost entirely restricted to the northern range of Trinidad.

This localized source area is clearly reflected in the pollen distribution pattern shown in text-figure 12. The restricted concentration north of Trinidad and Paria indicates wind transport, mainly during the season of southeasterly winds. Of course, sea currents must have modified the pattern by secondary transport westward. The similarity of distribution to that of *Hemitelia* is striking, and suggests a common main source.

The foregoing discussion has dealt with the distribution patterns of pollen types with only one main source area. A few patterns that have originated by supply from multiple source areas will next be shown. In extreme cases this leads to a diffuse distribution which is shown especially by pollen from ubiquitous and anemophilous species.

Symphonia globulifera (GUTTIFERAE)
Plate 1, figure 7

The pollen of this tree is easily recognizable by its large size, slightly angular outline interrupted by five irregular pores, and smooth, thick cavate wall, which has a typical corroded appearance. *Symphonia globulifera* is especially abundant in the extensive swamp forest covering the easternmost part of the Orinoco delta, but it also occurs regularly in the remaining swamp and marsh area and in the marginal forests along the lower river courses. The plant association in which it occurs here so abundantly is comparable with Lindeman's *Symphonia globulifera* marsh forest. In Trinidad, according to Beard, the tree occurs locally in a similar vegetation, but is also rather frequent in evergreen seasonal forest, *Mora* forest, and lower montane and montane rain forest. The occurrence of a single species in such widely different environments as tidal swamp on the

Distribution Chart

TABLE 1

Column headings (read top-to-bottom):

- SAMPLE STATION
- DEPTH IN CM.

CALCULATED:
- TOTAL POLLEN PER GRAM
- TOTAL FUNGI PER GRAM
- TOTAL TRACHEIDS PER GRAM
- TOTAL HYSTRIX PER GRAM
- TOTAL FORAMINIFERA PER GRAM

- TOTAL POLLEN COUNTED
- REWORKED POLLEN % OF TOTAL
- % ACROSTICHUM T.
- % ALNUS SP.
- % AMARANTHACEAE
- % ANACARDIUM T.
- % AVICENNIA SP.
- % BOMBAX AQUATICUM
- % CAESALPINIA SP.
- % CARYOCAR SP.
- % CEIBA T.
- % CERATOPTERIS SP.
- % COMPOSITAE
- % CROTON SP.
- % CYPERACEAE
- % ERYTHRINA SP.
- % GRAMINEAE
- % HEMITELIA SP.
- % ILEX SP.
- % MALPIGHIACEAE T.
- % MALVACEAE T.
- % MAURITIA SP.
- % MELIACEAE T.
- % MIMOSACEAE
- % MYRTACEAE
- % PCS. BAC
- % PALMAE SMOOTH GR.
- % PODOCARPUS
- % POLYGONUM
- % POLYPODIUM T.
- % PTERIS T.
- % PTEROCARPUS T.
- % RHIZOPHORA SP.
- % SAPOTACEAE
- % SYMPHONIA GLOBULIFERA
- % TERMINALIA T.
- % VIROLA SP.
- % VARIA

Pollen Distribution in Del[
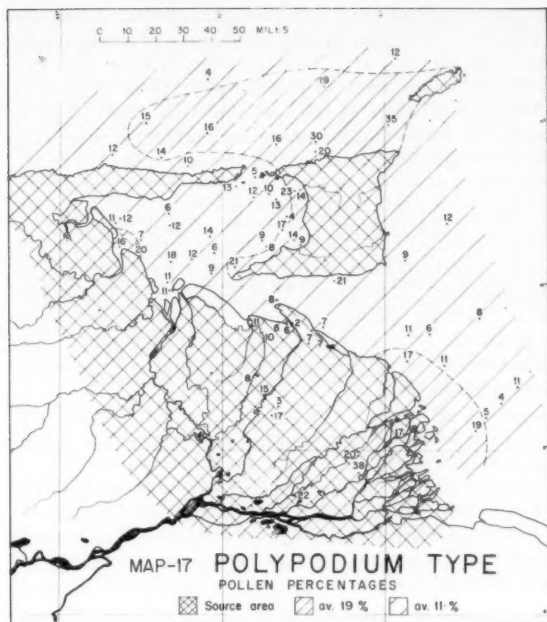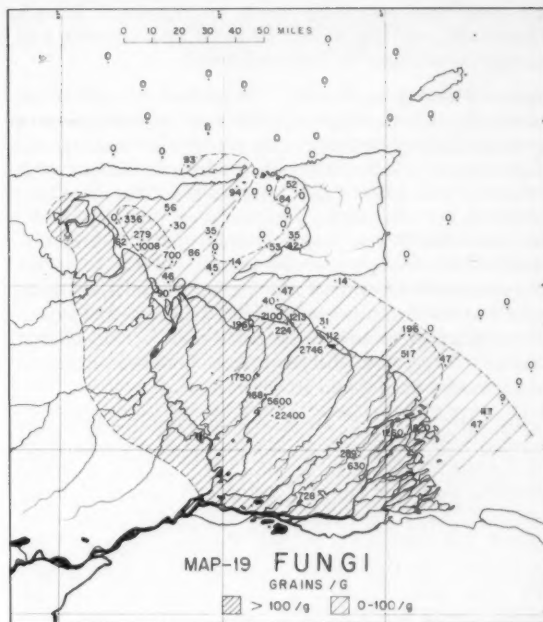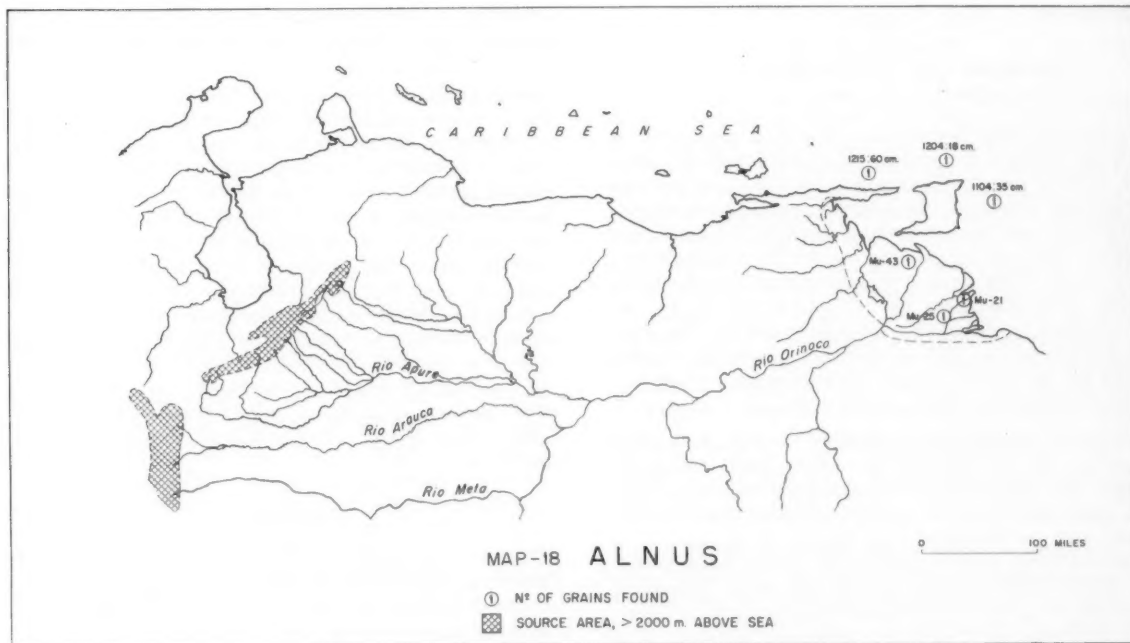
DIAGRAM 1
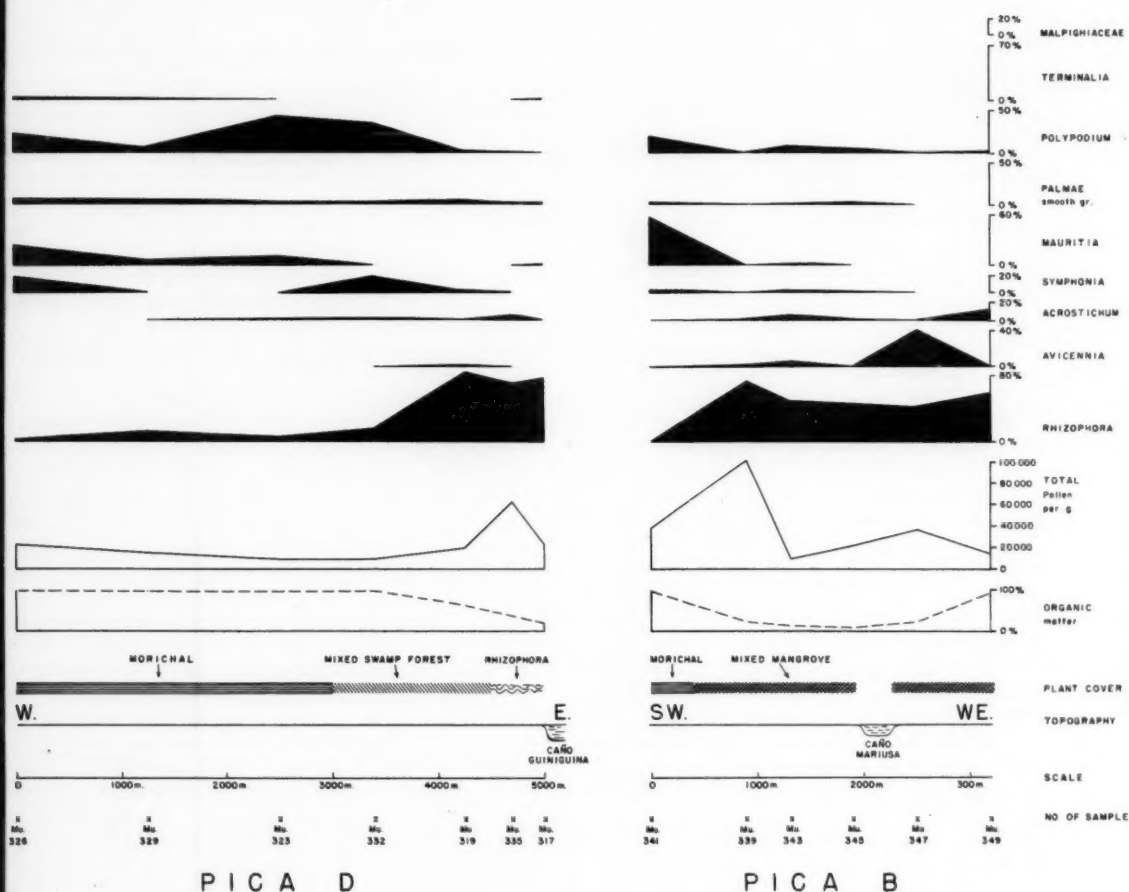
ution in Delta Deposits

TEXT-FIGURE 17

TEXT-FIGURE 19

TEXT-FIGURE 18

one hand and mountain forest on the other is very remarkable, and diminishes its value as a climatic and ecological indicator in fossil sediments.

In its distribution, shown in text-figure 13, *Symphonia* pollen shows the combined effect of multiple source areas and limited transport due to the relative heaviness of the grain. In the delta it reaches its highest percentages in the eastern part, especially in Pica E, where the tree is very abundant. In the central part, where the tree is decidedly less frequent, only scattered pollen is found. Offshore, opposite the eastern delta, the grains are conspicuously absent, although the tree is common up to the outermost vegetation belt. This is probably due to size selection, as a result of which the heavy *Symphonia* grains settle close to the coast line. Unfortunately, no samples were available from this area.

In the western Gulf of Paria, a local concentration can be observed. These grains are probably derived from the coastal swamp vegetation. In the central Gulf the *Symphonia* pollen is very scarce, which proves that the marine currents were able to transport the pollen over a short distance only. Around Trinidad another concentration appears, and it is possible that these grains may have been carried by wind transport from the forested areas on Trinidad. Finally, the rather high percentages found at stations 74 and 468 are probably indicative of reworking. This cannot be confirmed from their state of preservation, because reworked older *Symphonia* grains have almost the same appearance as Recent ones.

Terminalia type (cf. COMBRETACEAE)
Plate 1, figures 8, 8a

The identification of this pollen type is certain when it is well preserved. It is a very small, smooth-walled prolate tricolporate grain with narrow colpi and inconspicuous pores, and, as its most characteristic feature in equatorial outline, it possesses a depression between the colpi that suggests the presence of three more colpi without pores. This pollen type occurs in the genera *Buceras*, *Conocarpus*, and *Terminalia*, all of which belong to the Combretaceae. *Buceras* is not mentioned by Beard or Lindeman, but enough information is available on the other two genera to make it possible to outline the potential source area of this pollen type.

The genus *Conocarpus* is represented by a single species, *Conocarpus erectus*, which is one of the rarer mangrove plants. It could be expected in the delta, although it has not been observed by the author. In Surinam (see Lindeman) and on Trinidad (see Beard), it is rare. It is therefore likely that the bulk of the pollen grains under discussion have been derived from the genus *Terminalia*. This genus has very widespread distribution in different environments. In Trinidad, *Terminalia dichotoma* is a characteristic swamp species, and *Terminalia amazonia* is frequent in the marsh forest. The latter species, however, also occurs predominantly in evergreen, semi-evergreen, and deciduous seasonal forest, as well as in lower montane and seasonal montane rain forest. *Terminalia lucida* and *Terminalia catappa* are found in littoral woodland (see Beard). It is obvious from this list that the potential source area of this pollen type is large and widely distributed. If the fact that this pollen type is small and easily transported is also taken into account, the wide distribution shown in text-figure 14 is largely explained.

In the delta it is locally dominant in the eastern part (Picas E and F). The mother plant, unfortunately, could not be identified here. In the central delta it seems to be less abundant (Picas D and B). Offshore, it is distributed in a typically diffuse pattern, without distinct concentrations. It is therefore impossible to evaluate the influence of the various source areas and the nature of the transport medium.

GRAMINEAE

The large family Gramineae has one basic and easily recognizable pollen type, characterized by its single bordered pore and virtually smooth wall. Although a smaller and a larger type were observed, no attempt at further identification was made.

Gramineae are dominant in the semi-cultivated Venezuelan llanos and in other cultivated areas on Trinidad and Paria. In the delta they occur locally along river banks, where floating grass mats of *Leersia hexandra* are a common sight. In the upper part of the delta, *Gynerium sagittatum* borders the natural levees. They also occur in special types of herbaceous swamps. They are scarce in swamp forests and in upland forests.

The potential source areas are thus widely scattered, and this is clearly reflected in the pollen distribution shown in text-figure 15. In the delta, samples from the levees show a somewhat higher percentage than the backswamp samples, such as those taken in Pica E in swamp forest. Offshore, a very scattered distribution pattern emerges. Weak concentrations are found, first along the western coast of Trinidad, indicating some wind transport from the island, and secondly in the southeastern Gulf of Paria and in the Boca Vagre, indicating waterborne supply, presumably from cultivated areas upstream. Finally, the scattered high values found on the eastern shelf should be mentioned. These high values may indicate waterborne supply from the Guayana coast, where large swamp-savannah areas have been described.

COMPOSITAE

Here, the Compositae pollen comprises only typical tubiflorae and liguliflorae types. The tubiflorae type was by far the more common of the two. No attempt at further detailed identification could be made.

Compositae as a group scarcely occur in the typical swamp and marsh vegetation, nor are they abundant in the upland forests of the area under consideration. Most of the pollen found has probably been derived from the

savannah and cultivated areas on Trinidad, Tobago, and Paria, and in the Venezuelan llanos.

The pollen distribution shown in text-figure 16 indicates low values in the delta, especially in the back-swamps, but a significantly high value of 11 per cent in a levee deposit in the upper delta, in the cultivated area. Offshore, a vague concentration is visible in the central and eastern Gulf of Paria and along the northern coast of Trinidad and Paria, although Compositae pollen is notably absent in the western Gulf. It is also absent opposite the eastern delta except for a weak concentration in the northeast, which probably indicates some supply from the Orinoco tributaries.

Polypodium type (cf. POLYPODIACEAE)

The *Polypodium* type includes all monolete bean-shaped spores with either a smooth or a verrucate sculpture. It is a heterogeneous group, as this morphological type occurs in the Polypodiaceae as well as in some other fern families. The source area cannot be accurately defined; these spores may have been derived from nearly all the environments present in this area, except possibly the llanos and the cultivated areas.

Extensive fern swamps occur in the delta. Accordingly, the general distribution of the spores shows a wide range of variation related to the local frequency of the mother plants. In Picas E and F they are abundant, and in Pica D the transition between the *Rhizophora* belt and the morichal vegetation is marked by a dominance of *Polypodium* spores in the sediment (see diagram 1). In the coastal belt the percentages are lower (Pica B). Offshore they were found in all samples, often in considerable percentages (see text-fig. 17). Opposite the eastern delta seaward decrease due to size selection can be observed. Early settling of the rather large and sometimes heavily sculptured *Polypodium* type of spore is favoured. In the Gulf of Paria, there are only slight concentrations in the Rio San Juan estuary and along the western coast of Trinidad. On the northern shelf, rather high values north-northwest of Trinidad and west of Tobago indicate airborne supply from these islands. Thus, the influences of multiple source areas and mass production have resulted in wide and diffuse distribution.

A similar distribution pattern is shown by various other pollen types, such as *Acrostichum*, Amaranthaceae, Cyperaceae, *Ilex*, *Virola*, and psilate Palmae. Other types are less common and have more scattered distribution; these include *Bombax aquaticum*, *Caesalpinia*, *Caryocar*, *Ceiba*, *Ceratopteris*, *Croton*, *Erythrina*, Malpighiaceae, Malvaceae, Meliaceae, Mimosaceae, Myrtaceae, *Polygonum*, *Pterocarpus*, and Sapotaceae. For *Erythrina* and *Pterocarpus* it was possible to establish that the scarcity of their pollen, which is in strong contrast to the abundance of the mother plants, is due to the small amount of pollen liberated by the papilionaceous flower types of both genera.

Alnus sp. (BETULACEAE)
Plate 1, figure 9

Very characteristic *Alnus* pollen was found as single grains in six samples, the locations of which are indicated in text-figure 18. In the delta they were recovered from levee deposits, and on the shelf they were found in cores at depths of 35, 60 and 180 cm.

The nearest occurrence of the species *Alnus Mirbelii* and *Alnus jorullensis* is in the Andes, at altitudes between 2000 and 3000 meters, in the Venezuelan states of Trujillo, Mérida, and Táchira, and in Colombia (see text-fig. 18). Within this area, *Alnus* grows preferably along the banks of mountain streams and brooks. It is quite evident that these grains cannot have been wind-transported to the area of deposition, but must have been carried by the Orinoco River system from the Andean sources, over a distance of more than 500 miles, to the delta and shelf. Of course, this is an exceptional case, and *Alnus* has been especially favoured because it is a very prolific pollen producer and grows in a favourable habitat beside running water, but nevertheless its average quantity in the area of deposition scarcely amounts to 0.5 per mille. Some of these grains, however, may have been reworked from Pleistocene deposits.

3) *Distribution of other microfossils:*

FUNGI
Plate 1, figure 10

Spores and hyphae of fungi are extremely abundant in most delta deposits, where these micro-organisms play an important part in the decaying processes which liquidate most of the plant litter produced by the exuberant swamp vegetation. In text-figure 19 the amount of fungal spores per gram of sediment is plotted. Their abundance in the delta is obvious. Offshore concentrations are found opposite the northeastern corner of the delta and in the western part of the Gulf of Paria. The smaller amounts in the Boca Vagre and San Juan estuaries can be explained in the same way as the lower pollen content, that is, by the comparatively larger amounts of coarser mineral fractions. A continuous belt of medium values is found opposite the entire delta, along both the southwestern and western Trinidad coasts, and along part of the northern coast of Paria. In the central and eastern Gulf and on the outer shelf, no fungal spores were found.

It may be assumed that fungal spores, in comparison with pollen, are less subject to initial wind transport because they are generally produced in the thick mat of decaying plant material at the soil surface of a generally very dense plant cover. They are probably liberated mainly from the back-swamp soils during heavy rainfall or by erosion of river banks. Once freed, they may be transported over fairly large distances because of their generally small size (10–30μ).

The offshore distribution pattern indicates multiple source areas and moderate distances of transport. Apparently, they are liberated not only from delta soils but also from upland Trinidad soils. The lack of initial wind transport causes less wide distribution in comparison with *Rhizophora* pollen. In the delta they are largely liberated by erosion, and thus tend to be concentrated in the lower water levels in the estuaries. Because of the estuarine circulation pattern, the particles from these levels have a smaller chance of escaping offshore than pollen, which first settles on the surface and which is more easily carried off seaward. The local concentrations opposite a few delta estuaries may indicate areas where deposits particularly rich in fungi are being eroded.

CUTICLES

In text-figure 20, the sizes and abundances of plant cuticles are plotted, expressed on a scale of five points. Size and abundance are generally correlated. In delta sediments, cuticles are very abundant and of large average size. The cuticles found offshore, concentrated in a belt opposite the large delta estuaries, have been derived by stream erosion from these delta sediments. Both the abundance and the size of the cuticle fragments decrease rapidly offshore, and only the smallest fragments escape to the outer shelf. Some secondary concentrations at stations 74, 180, and 468 may indicate the presence of locally reworked material. The similarity between the cuticle and the fungus distribution is evident.

TRACHEIDS
Plate 1, figure 11

The distribution of tracheid remains is indicated in text-figure 21. These peculiar tissue fragments have all been reworked from pre-Eocene deposits, of which they are characteristic. They are mainly eroded by the Orinoco headwaters in the Andes. The plants from which they originated are not known with certainty, but presumably are gymnosperms. In the levee deposits they are frequent, but offshore they are mainly concentrated in a belt opposite the larger estuaries. Some secondary concentrations along the southwestern Trinidad coast and locally in the northern Gulf of Paria indicate reworking from other local sources. Reworking is also indicated here by the distribution of reworked pollen. On the outer shelf, tracheid remains are virtually absent.

HYSTRICHOSPHAERIDAE
Plate 1, figure 12

The Hystrichosphaeridae are a group of planktonic organisms of little-understood systematic position. Most probably they represent the cyst-like resting stage of certain unicellular algae of the dinoflagellate group. Morphologically they are characterized by their small size (40–60μ) and smooth wall, which is covered with numerous hooked, hollow spines. It is possible to distinguish various morphological types, but as the systematic relationships between these types is not yet

known, they are here placed in a single group and referred to as "*Hystrix*."

The distribution of *Hystrix* per gram of sediment is shown in text-figure 22. It is absent in the littoral zone opposite the Orinoco delta, and is concentrated mainly in the eastern Gulf of Paria, close to the Trinidad shore. This distribution pattern suggests that *Hystrix* may be a marine organism, which probably cannot flourish below a certain salinity, but the turbidity in the littoral zone may also have been a limiting factor.

The concentration in the eastern Gulf suggests that optimum conditions for the development of *Hystrix* prevail there. Hydrographic data for this area indicate the presence of clear water with a chlorine content of 18–22 parts per thousand and with temperatures up to 29^0 C., which is slightly higher than the temperature of normal ocean water as it is carried into the Gulf by the Atlantic equatorial current through the Serpent's Mouth. It is possible that the relatively high temperature is favourable for the development of *Hystrix*. It is also worth mentioning in this connection that the *Hystrix* specimens from this part of the Gulf are larger and better developed than those from the outer shelf, suggesting some direct environmental influence on the growth and morphological appearance of *Hystrix*. On the other hand, the abundance of *Hystrix* is also related to the rate of sedimentation, and the influence of this factor is hard to isolate without further detailed ecologic study of the living population. For the time being, *Hystrix* can be considered only as a general facies indicator for a marine environment.

FORAMINIFERA
Plate 1, figure 13

In many samples, the remains of small foraminiferal tests were found, which had survived the chemical treatment. The most common type found was the probably chitinous inner lining of tests, left after solution of the calcareous outer layers. In a few cases, fluoride replacement of the original calcareous test was observed, as described by Grayson (1956). The distribution of the first-mentioned group is shown in text-figure 23.

Since there was at first some doubt whether or not these remains, which occur either in a rotaloid or bolivinoid form, were actually derived from foraminifera, because of their small size and different appearance, it was decided to dissolve some known foraminifera under the microscope in order to find out whether any remains were left. These experiments were made by B. B. 't Hart, palaeontologist with Shell Condor (Colombia). The sample taken at station 1041 was washed in the ordinary way for foraminiferal study, with floating elements preserved as is normally done for ostracode study. The foraminifera of the finest fraction (200 mesh) were separately transferred to a glass slide and treated with a 10 per cent HCl solution. The average diameter of this foraminiferal fraction proved to be 0.16 mm., and all specimens tested were megalospheric forms belonging to
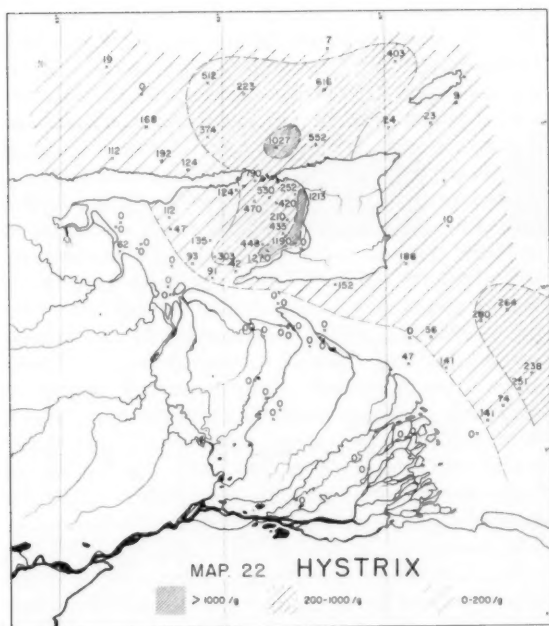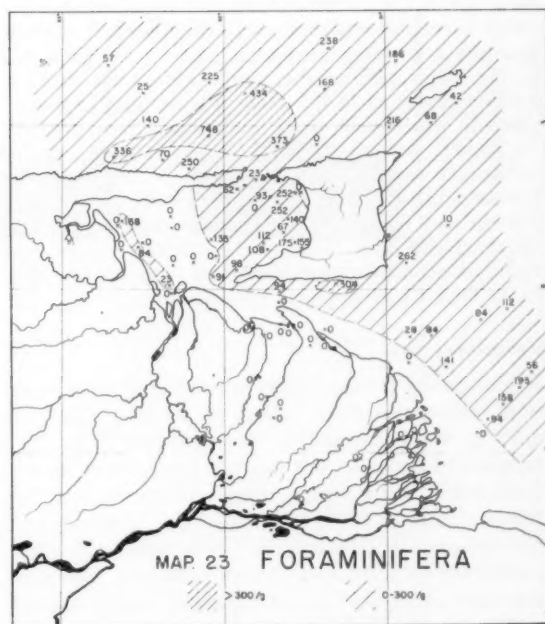
TEXT-FIGURE 20

TEXT-FIGURE 21

TEXT-FIGURE 22

TEXT-FIGURE 23

21
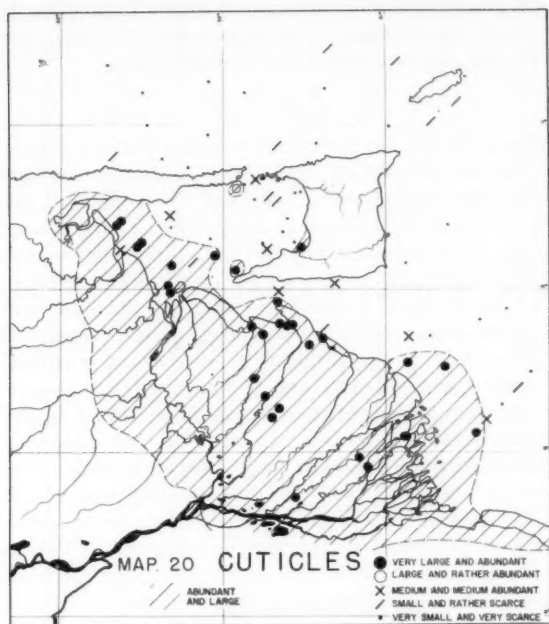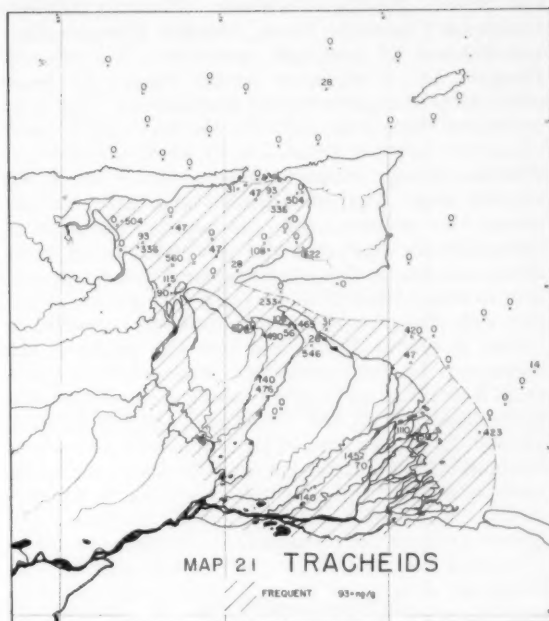
the genera *Bolivina, Cassidulina, Cibicides, Eponides, Globigerina, Globorotalia, Nonion, Planulina, Quinqueloculina,* and *Siphonina.* Of these, only specimens of *Cibicides* and *Planulina* left a chitinous residue similar to those observed in the palynological preparations. This is in agreement with data given by Piveteau (1952), who states that only the Rotaliidea, to which *Cibicides* and *Planulina* belong, possess a chitinous inner test in the juvenile stage. The other genera apparently do not possess this property, with the possible exception of *Quinqueloculina,* which may develop a chitinous test under certain conditions. Grayson's statement that he was not able to detect these chitinous inner tests proves, therefore, only that the specimens he dissolved happened to belong to genera that do not have this property. His subsequent conclusion that these inner coats do not exist at all is therefore an invalid generalization. Wilson and Hoffmeister (1952), and later van Veen (1957), have already drawn attention to the phenomenon of microforaminifera and have arrived at the correct conclusions concerning their origin. In this connection it is worth noting that Faegri and Iversen (1950) mentioned and correctly interpreted the occurrence of chitinous remains of marine foraminifera in their pollen residues. The foraminiferal nature of the microfossils under discussion may therefore be taken as proven, although a more detailed study of these small but sometimes fully grown representatives of a restricted group of genera is evidently desirable.

Returning now to their distribution pattern, which is given without any attempt at specific determination but which mainly covers remains of Rotaliidea, it appears that they are widely distributed except in the delta and in the major part of the pro-deltaic-littoral zone. A notable exception to this pattern is the small elongate patch in which they occur in the latter zone opposite the western estuaries. It is of interest to note that this occurrence was not detected by Kruit in his study of the Recent foraminifera in the Gulf of Paria (van Andel, Postma and Kruit, 1954). Generally speaking, it may be concluded that foraminiferal remains of the type under discussion are more abundant in the marine than in the littoral and estuarine environments.

Investigation of cores

Although the present study is essentially concerned with microfossil distribution in Recent sediments only, it was felt desirable to investigate a few core samples in order to test the homogeneity of microfossil distribution in time. Three cores were selected, taken at stations 1101, 1204 and 1215. These showed the deepest penetration in areas which lie comparatively far from local deltaic influence, and their lithology consists of a homogeneous clay sediment, which was also a favourable factor. The cores were examined at 10–20 cm. intervals, but unfortunately the top and bottom layers of the cores were no longer available, as the material had been used for other purposes. The results are shown in diagram 2, where the variations in abundance are indicated for the most important microfossil groups.

Core 1101

From 70–195 cm., the total pollen content is higher than at the surface, but below 195 cm. a sharp decrease downward is observed to values that are lower than those found at the surface. This indicates that, in the period represented, there was a considerable shift in the pollen distribution pattern, which in itself is not surprising, as the core was taken rather close to the large eastern estuaries. There is little variation in the per cent of reworked pollen, and the low values found off the eastern delta are typical both of the surface and of deeper layers. *Mauritia* percentages are uniformly very low. *Avicennia* percentages average 3 per cent both at the surface and in the core. *Rhizophora* percentages fluctuate in the core at approximately 50 per cent, which is normal in the surface area. If the fluctuations are compared with the total pollen curve, it appears that a decrease in the total pollen content is always accompanied by an increase in *Rhizophora* percentages and vice versa. This relationship in a vertical direction is identical with the one observed in the surface sediments in a section perpendicular to the coast, and the explanation given previously holds here too: Progressive sorting tends to increase the proportion of small *Rhizophora* grains seaward. In the core, this relationship is not absolute because the samples at 225 cm. and 255 cm., which have the lowest pollen content per gram, do not show the highest percentage of *Rhizophora.* This indicates that in this period the *Rhizophora* vegetation suffered a setback in areal extent as compared with the higher part of the core, where *Rhizophora* pollen was supplied in larger quantities. In agreement with surface observations in this area, the mountain element is almost completely unrepresented in the core. Two single *Hemitelia* grains recovered may have been carried by long-distance transport from an area other than Trinidad. Only scattered grains of *Symphonia globulifera* were found in the core, which is in line with the virtual absence of these heavy grains at the surface in this area. An average of 9 percent of the *Terminalia* type in the upper six samples checks very closely with the surface average. The lowermost sample shows a significantly lower value. Gramineae show very low frequencies in the upper part of the core, in accordance with surface values, but the lowermost sample shows a significant increase. Compositae show a similar pattern: Low frequencies in the upper part, in accordance with surface distribution, but a significant increase in
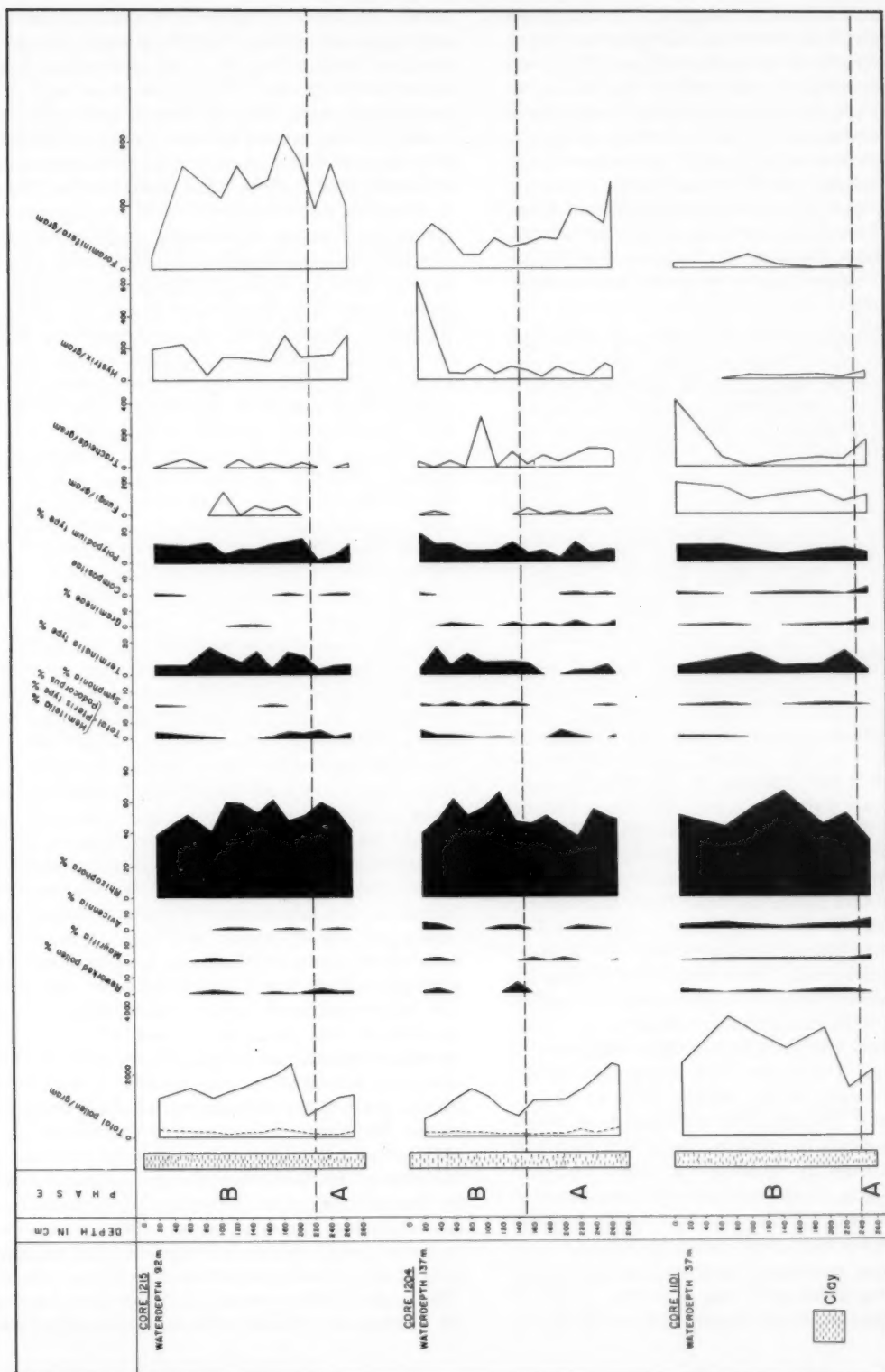
DIAGRAM 2

MICROFOSSIL DISTRIBUTION IN CORES

percentage in the lowermost sample. The Polypodi-aceae type of spore averages about 9 per cent in the core, which checks with surface values. The fungi concentration shown in the surface distribution at stations 1100 and 1101 appears to have been present during the entire time-span covered by the core, although there is a slight decrease in the lower part. The high tracheid content found at the surface is evidently an exceptional occurrence. *Hystrix* shows low values throughout the core, in agreement with surface values. Foraminifera values are slightly higher in the upper part of the core, and conform to surface values.

Summary of development: The variations in microfossil content in the upper 2 meters of the core are rather small, and indicate fluctuations in the hydrographic regime such as could have been caused by variations in the Orinoco discharge or by slight shifts in the positions of the eastern estuaries. In the two lowest samples, however, a more marked change in micro-fossil content appears. The total pollen content drops sharply, and a decrease in *Rhizophora* per-centage is coupled with an increase in Gramineae and Compositae. This probably reflects a somewhat more profound change in pollen supply and sedi-mentation, which may have been caused partly by a climatic change.

Core 1204

From the surface down to 80 cm., the total pollen content shows a very regular and significant in-crease, which is then followed by a similar decrease. A small increase is seen next, and then, from 160 cm. to 200 cm., the values remain constant. Finally, down to 270 cm., a gradual and significant increase occurs, attaining values that are four times higher than those found at the surface. These fluctuations are indicative of shifts in pollen supply, which, because of the distant location of the core, far from the delta source, must have some regional signifi-cance. Reworked pollen is observed only occasion-ally, in line with surface observations in this area. *Mauritia* occurs scattered in the same frequency as at the surface. The rather high percentage of *Avi-cennia* found at the surface persists down to 40 cm., then scattered occurrences are found at lower levels. It is hard to explain these high *Avicennia* values other than by assuming that they represent reworked grains, an assumption which is supported by the coincidence of the higher *Avicennia* percentages with the two maxima of reworked grains.

The *Rhizophora* percentage is lower in the surface layer than it is between 60 cm. and 120 cm. Below 120 cm., values show a tendency to decrease again.

There is a certain agreement between the curves for total pollen and for *Rhizophora*, especially in the upper part of the core. Here, the total pollen maxima between 40 cm. and 120 cm. also show high *Rhizo-phora* percentages. The minima in total pollen con-tent at the surface and between 140 cm. and 220 cm. also show a lower average *Rhizophora* percentage. The strong increase in total pollen below 220 cm. is, however, not entirely matched by a comparable *Rhizophora* increase. This parallel trend is the reverse of what has been described for core 1101, and can be explained by different supply conditions in the area of core 1204. Here we are in an area where the *Rhizophora* share in the waterborne-pollen mass is decreasing westward because the largest part has already settled out and the airborne supply of other types is becoming more prominent. This wind-sup-plied share may be assumed to be constant, so that any drop in the delta supply, which here consists of more than 80 per cent *Rhizophora*, will cause a relative increase in the airborne pollen. In core 1101, this compensating influence was absent, which ex-plains the difference. As was to be expected from the surface data, the mountain element in the pollen flora is found regularly, and decreases only with high *Rhizophora* values. This confirms the idea that the supply of this element remained essentially con-stant during the time of deposition of the core. There appears to have existed a rather persistent supply of the heavy *Symphonia globulifera* pollen in the area north of Trinidad, at least for the period covered by the upper part of the core. These grains must either have been carried by wind from Trinidad or have been reworked, as the probability that they were carried by water from the eastern Orinoco delta is negligible. It is, at present, difficult to decide be-tween these two possibilities. *Terminalia* values are higher in the upper part of the core than in the lower part. At the surface, the general trend in the area again appears to be toward slightly lower per-centages. Gramineae are slightly more frequent in the lower than in the upper part of the core. Com-positae are very scarce throughout. *Polypodium* forms a mainly windblown element, derived from Trini-dad and Tobago, and consequently shows a trend in the percentage fluctuations which is the reverse of the *Rhizophora* curve. Fungi are more frequent in the lower half of the core, and their decrease up-ward is in line with their almost complete absence in the surface layers of the area. Especially in the lower part of the core, below 100 cm., tracheids seem to have been supplied regularly and sometimes abundantly, indicating reworking from close by. The source of this material probably must be sought in Pleistocene and older Holocene sediments, which

have been locally attacked by wave erosion. In the youngest layers and at the surface, this supply has almost ceased. The rather high *Hystrix* values found at the surface appear from the core record to be a relatively recent feature, for which it is hard to find a satisfactory explanation at present. Foraminiferal content fluctuates rather strongly, but shows, nevertheless, an increasing trend in the lower 40 cm. of the core.

Summary of development: The rather well-marked variations in microfossil content in core 1204 center around the marked but regular variations in total pollen content and the alternation between the curves for *Rhizophora* and the windblown elements. If the total values for the windblown pollen per gram of sediment are computed, a nearly straight line is obtained, with only a minor increase near the bottom, as can be seen from the chart, where it is plotted as a dotted line. Furthermore, the increase in *Terminalia* percentage in the upper part seems significant.

The constancy of the windblown supply indicates that no major changes in shoreline position took place during the period covered by the core sediments. The variations in total pollen content are therefore most probably attributable to the same causes as were indicated for core 1101, that is, changes in the hydrographic system caused by variations in Orinoco discharge. The location of the core makes it improbable that these were caused only by local shifting of estuaries, but suggests instead a more widespread cause.

CORE 1215

From the surface down to 120 cm., the total pollen content remains almost constant, but farther down a gradual increase is noted, reaching a maximum at 190 cm., after which a sharp drop takes place. This is followed by a renewed increase which levels off farther down. Reworked pollen is scarce throughout, in accordance with the general surface distribution, but seems to be slightly concentrated in the lower part. *Mauritia* is almost completely absent, in accordance with the general surface distribution. *Avicennia* occurs scattered, with a frequency similar to that found at the surface. In this core also, a parallel trend is observed in both the curve for total pollen and the curve for *Rhizophora* per cent. The main supply of *Rhizophora* at this location must have been through the Dragon's Mouth, but some contribution from the eastern shelf is also to be considered. In relation to the two supply directions, the core is located in the zone of decreasing *Rhizophora* supply and increasing windblown share in the

pollen total. The explanation of the parallel trends between total pollen content and *Rhizophora* per cent given for core 1204 therefore holds here also. As in core 1204, we see here also an alternation between the trends for the mountain-pollen curve and the *Rhizophora* curve. The same explanation can be given as for core 1204. *Symphonia globulifera* is very scarce, in accordance with the general surface distribution. From 0–210 cm., rather high and strongly fluctuating *Terminalia* percentages are found, whereas in the lower part, percentages tend to decrease somewhat. Gramineae and Compositae are both very scarce, in accordance with the general surface distribution. The *Polypodium* curve shows a trend similar to that in core 1204, with alternations of its peaks with *Rhizophora*. The explanation is the same: a constant supply of windblown *Polypodium* spores and a variable supply of waterborne *Rhizophora* pollen grains. The curve for fungi content shows peculiar maxima between 110 cm. and 200 cm. In the upper part, fungi are absent, in accordance with the general surface distribution. Tracheids are rather regularly present in low numbers, which contrasts with their absence at the surface. This is similar to what was observed in core 1204, although the values reached there are higher. Values for *Hystrix* fluctuate rather strongly but are, on the average, in line with those found in the general surface area. The surface values for foraminifera are considerably lower than those from 60 cm. downward. This suggests that the area with a high foraminiferal content at the surface north and northeast of station 1215 may formerly have had a wider distribution.

Summary of development: The most striking variations in microfossil content are visible in the curves for total pollen, *Rhizophora*, the mountain element, and *Terminalia*. If the curve for total windblown pollen per gram is computed, slightly more variation is observed than in core 1204. Changes in supply from the Orinoco delta dominate the pollen diagram here also. The high values for *Hystrix* and foraminifera found throughout the core emphasize the depositional environment, which differs from that of the other cores.

DISCUSSION OF CORES

From the preceding detailed descriptions it will be clear that the average microfossil content in the upper part of the cores is typical of their respective environments, with respect to both pollen supply and biofacies characteristics. It is only in the lower part that marked deviations from the present-day situation are indicated. The relations between the windblown element and the delta-supplied element

in the pollen content of the sediments accumulating on the northern shelf, as deduced from the surface distribution, are confirmed by the results of the core investigation. The seaward increase of *Rhizophora* at the surface due to progressive sorting is also confirmed by the results of the core study.

A closer study of the variations in pollen content suggests that they may have a regional cause. The evidence for this lies, first of all, in the fluctuating total pollen content. From the surface downward, all three cores show a gradual increase in total pollen content, followed by a more sudden decrease to values that are equal to or even lower than those found at the surface. This minimum, which is found at 225 cm., 140 cm., and 210 cm., respectively, in cores 1101, 1204, and 1215, is followed by a renewed gradual increase downward. This earliest phase is also characterized by decreasing *Rizophora* and *Terminalia* percentages, while grasses and Compositae increase in frequency. In agreement with their more comparable locations in relation to supply cores 1204 and 1205 show a closer similarity to each other in the trends of their pollen curves than they do to core 1101.

The fact that the total pollen content rises only in the lower part of core 1204 up to values more than four times as high as those found at the surface suggests that this core penetrated the oldest sediments. On the basis of this evidence, two developmental phases are tentatively distinguished. The older, Phase A, appears to be characterized by a regularly decreasing total pollen content, an average *Terminalia* percentage of 4 per cent, and frequencies (per cent of samples in which they occur) of 55 per cent each for Compositae and Gramineae. Phase B is marked first by a rather sudden increase in total pollen content, followed by a decrease; high *Rizophora* values; an average *Terminalia* percentage of 10 per cent, and frequencies for Compositae and Gramineae of 13 per cent and 18 per cent, respectively.

Although a full evaluation of the significance of this regional development must await a more detailed investigation of additional core material, it seems worthwhile to offer a few suggestions as to its possible ultimate cause. The main factors operating in the area that may have shown their influences in the pollen diagram are: 1) The local shifting of Orinoco estuaries due to normal sedimentary processes; 2) sea level changes; and 3) climatic changes. Shifting the position of a main estuary changes the total pollen distribution and the percentage ratios of the various types. Van Andel has found evidence that a shift of the main Orinoco discharge from the eastern delta toward the Macareo and Boca Vagre estuaries took place about 700 years ago. It appears possible that the sharp decrease in core 1101 from 70 cm. upward, and in core 1204 from 80 cm. upward, may reflect this change, as this shift would tend to reduce the delta-pollen supply at these locations. There is not such a marked decrease visible from 100 cm. upward in core 1215, probably because the delta supply reaches this location via the Dragon's Mouth from the western estuaries, which increased their discharge simultaneously. Further study of cores, especially from the Gulf of Paria, is required in order to test this hypothesis.

Sea-level changes may cause general shifts in the positions of coast lines, especially of the flat delta coast. Van Andel cites evidence of a regression of sea level toward the 6–7 meter depth line, which he thinks took place from 1000 to 1500 years ago, and which was followed by a transgression about 1000 years ago. The sharp increase in total pollen content found in core 1101 between 230 cm. and 190 cm., and in core 1215 between 210 cm. and 190 cm., as well as the more gradual increase in core 1204 between 140 cm. and 80 cm., may be due to this lowering of sea level, resulting in a seaward movement of the delta front. The extent to which the lines of equal pollen content migrated seaward in this case can be deduced from the depth contours, and is found to be roughly proportionate to the increase in total pollen content registered in the cores at the depths indicated.

Climatic change may be expressed both by changes in the composition of the vegetation and by changes in the amount of Orinoco discharge as a result of changes in rainfall in the drainage area. The only indication that suggests a climatic change is found in the increase of *Terminalia* and decrease of Compositae and Gramineae at the boundary between phase A and phase B, but the nature of this change cannot yet be indicated with the scarce data available.

Notwithstanding the provisional nature of these reflections on the causal relations of the changes observed in the diagrams, it is tentatively concluded that these changes can be used for time-stratigraphic correlation, as they appear to be of a regional nature. The boundary between phases A and B in particular is regarded as closely approaching a time line. Unfortunately, no radiocarbon dating is possible in the pure clay cores that are most suitable for palynological study, and direct confirmation of this hypothesis must await correlation with nearby cores in which dated mollusk beds are present.

An estimate of sedimentation rates at each location can be given, if the correlation suggested above proves to be correct. Core 1101 shows the fastest rate of sedimentation, in accordance with its position in the fluvio-marine environment, close to the large eastern estuaries. Core 1204 has a much slower rate of sedimentation, which is evidently related to its distance from the source of sediment in the eastern estuaries. Core 1215 shows a rate of sedimentation that is only slightly lower than that found in core 1101. In this connection it is of interest to note that apparently no direct relationship between rate of sedimentation and total pollen content exists, as the average pollen content in phase B of core 1215 is roughly intermediate between those of cores 1101 and 1204, although the thickness of phase B is the same as in core 1101. This is not surprising, as the sources and supply conditions of clay and pollen are naturally different.

It is also of interest to investigate to what extent *Hystrix* and foraminiferal content are related to the rate of sedimentation. There is, again, no direct relationship, but the increase in both *Hystrix* and foraminiferal content in the upper part of core 1204, as well as the decrease in foraminiferal content in the upper part of core 1215, may tentatively be assumed to have been connected with the above-mentioned shift in the supply of sediment about 700 years ago.

If the tentative absolute dating proves to be correct, it will be possible to calculate both the rate of sedimentation for phase B, and the average total amount of pollen settling per unit of time/surface, the so-called "absolute pollen frequency." Calculated for phase B, the average rate of sedimentation/100 years is 14 cm. in cores 1101 and 1215, and 9 cm. in core 1204. These values are somewhat lower than the estimates given by van Andel for the central Gulf of Paria. In cores 1204 and 1215, this difference is in line with their greater distance from the sediment source. These values check surprisingly well with estimates made indepentently by Koldewijn (1958) for the northern shelf. His estimate for core 1204, based on the depth of the top of the Pleistocene, which can be traced on the echo-sounding graph, is 8 cm./century, which is virtually identical with the palynological estimate of 9 cm./century. His estimate for core 1215 is also 8 cm./century, which is markedly lower than the palynological estimate of 14 cm., but here it must be borne in mind that the latter value refers to the top layer of Holocene sediments, whereas the former value is based on the thickness of the entire post-Pleistocene sediment layer. This difference indicates an in-creased rate of sedimentation in the youngest Holocene phase, which may have been due to an increased supply of sediment to this area during the past 700 years, caused by the shift in the Orinoco discharge toward the Macareo and Boca Vagre estuaries referred to previously. Thus the palynological and sedimentological data are in essential agreement, and this constitutes a strong argument for the correctness of the palynological correlation and the subsequent stratigraphic interpretation.

The absolute pollen frequency can next be calculated in the same way as was already done for the Gulf of Paria, by assuming an average water content of 60 per cent for the fresh sediment (van Andel), and a specific weight of 2.0 for the clay material. The following values are then obtained: Core 1101, 315 grains/cm²/year; core 1204, 69 grains/cm²/year; core 1215, 171 grains/cm²/year.

These values, and the figures given earlier for the Gulf of Paria, can be compared with the values obtained from direct measurements by Hesselman for the Gulf of Bothnia and by Faegri for the North Sea (Faegri and Iversen, 1950). These figures, however, deal with windblown pollen only, and a direct comparison can be made only for cores 1204 and 1215, in which it has been estimated that a minimum of 10 per cent is windblown. This gives minimum values of 7 and 17 windblown grains/cm²/year for cores 1204 and 1215, respectively. These figures are much lower than those found in the Gulf of Bothnia, but are quite comparable to the value of 17 grains/cm²/year found in the Norwegian Sea 450 km. from the Norwegian coast. The much smaller distance off the coast of cores 1204 and 1215 in comparison to the latter locality is counter-balanced by the preponderance of adverse north-easterly trade winds north of Trinidad.

Thus it appears that the results of the investigation of the three cores not only are of interest as a background for understanding the Recent distribution patterns of pollen and other microfossil groups, but also that they reveal important features which can be utilized in the study of Holocene depositional history and in the interpretation of palynological changes in general.

Recognition of sub-Recent sediments

On the southeastern Trinidad shelf, sediments that are of proven or supposed Pleistocene age lie at or near the surface, pointing to reduced sedimentation due to wave action in the shallow areas there. Several samples were investigated palynologically in order to confirm, if possible, the supposed Pleistocene age.

The salient features in the microfossil content of these samples are given in the table below.

Station	Depth	Total pollen/g.	Total *Hystrix*/g.	Per cent *Rhizophora*	Radiocarbon age
1026	0–10 cm.	1568	0	6	
1103	195 cm.	2610	0	41	
1104	35 cm.	3696	0	8	
1109	100 cm.	12,500	0	27	$17,820 \pm 600$ yrs.
1142	192 cm.	1453	0	11	
1181	15 cm.	1250	0	1	

If these figures are compared with the values typical of the Recent sediments in this area, it will be clear at once that these are sediments that have been deposited in an environment differing strongly from the one prevalent today. Pollen contents are much higher than normal in the Recent surface layer, pointing, in the case of sample 1109 at 100 cm. depth, even to deltaic or very near-shore conditions. In general, all samples seem to have been deposited during a period in which the coast line had migrated far seaward, which would have been possible only with glacial eustatic lowering of the sea level, thus making a Pleistocene age highly probable. In sample 1109 at 100 cm. depth, this has actually been proved by radiocarbon dating. *Rhizophora* percentages are much lower than those found today in the surface sediments, which points to a different paleo-geography. The remaining pollen types also occur in different ratios. Finally, Hystrichosphaeridae are completely absent, in strong contrast to their regular occurrence in the Recent muds. Although direct proof of a Pleistocene age cannot be provided by palynological examination without further study of proven Pleistocene sections, the assumptions of the sedimentologists appear to be well justified, and a Pleistocene to early Holocene age can be safely assigned to the samples indicated.

DISCUSSION OF RESULTS
Transport and sedimentation of pollen

The preceding analysis of variations in the pollen content of sediments at the surface and in cores has made it possible to follow the processes of transportation and sedimentation of pollen. The relative importance of wind versus water transport has been largely evaluated from the foregoing.

The dominating factor is the presence of a large delta which acts as a major pollen source and transport agency by its discharge of water. Over-representation of pollen produced by local swamp vegetation is the rule in delta sediments because of restricted transport facilities, but offshore the pollen suspension in water is thoroughly mixed by turbulent flow and widely distributed by marine currents.

Pollen settles gradually during transport, which results in a decrease in the total pollen content away from the source area. Settling is accompanied by a certain degree of size selection, the smallest grains being relatively concentrated the farthest seaward. In addition, the effect of the mainly airborne supply from Trinidad and Tobago is apparent, but quantitatively it remains of only minor importance.

The airborne phase of pollen transport, which in general is of short duration for delta-produced pollen and much longer for pollen from Trinidad and Tobago, was not extensively investigated. Pollen sampling of the atmosphere above the Gulf of Paria produced negative results. However, a tentative estimate of the absolute frequency of windblown pollen in the two cores from the north Trinidad shelf proved possible, and is in line with observations made by other authors. The waterborne phase of pollen transport could, on the contrary, be further analyzed in relation to the large amount of hydrographic and sedimentological data discussed by Van Andel and Postma and by Koldewijn.

For a direct comparison of the distribution of pollen and sedimentary particles, the settling velocities of pollen grains in water will have to be determined. The first difficulty is the determination of the specific weight of pollen, both in the fresh state and as an empty exine. Erdtman (1943) indicates a range of 0.4–1.2 for fresh pollen. This suggests that many pollen grains will float for a time before settling, a fact that is well known, especially of coniferous pollen. The specific weight will probably increase when the living content dies and is replaced by water. Wolfram (1954) indicates a range of 1.1–1.2 for the specific weight of sub-Recent pollen. The settling velocity of these empty pollen exines is also dependent on their size, shape and ornamentation, all of which are extremely variable. According to Stoke's law, the settling velocity of a pollen grain with a diameter of 0.03 mm. and a specific weight of 1.2 would be 4 cm./hour. Settling experiments carried out by the author with pollen derived from Recent Orinoco sediments, however, gave higher values. For *Rhizophora* pollen (20μ, spherical, smooth), a settling velocity of 7 cm./hour was found, and for *Symphonia* pollen (40μ, suboblate, smooth), 17 cm./hour. On the basis of an average settling speed of 12 cm./hour, pollen grains would then bear comparison with mineral particles of 0.004–0.008 mm. diameter (fine silt). A direct comparison is now

possible between the distribution of water-transported pollen from the delta and the distribution of other suspended matter which is also mainly derived from the delta estuaries. According to Postma, the average grain-size of the suspended floccules in the Gulf of Paria is 0.015 mm., and the material suspended at the estuarine surface is even coarser and is estimated at 0.03 mm. As the settling velocities of these particles are of the order of 80–100 cm./hour, they must have been kept in suspension by considerable turbulence, otherwise they could not have been distributed over the entire Gulf of Paria. Thus, for pollen grains, with their considerably lower settling velocity, transport in suspension over the Gulf of Paria is theoretically possible. This is in agreement with the distribution pattern actually found. The heavier grains are mainly restricted to the coastal belt opposite the estuaries, where the largest amounts of pollen also settle, but the light *Rhizophora* pollen escapes in large quantities, together with the suspension of the finest clay particles, through the Dragon's Mouth onto the northern shelf. Even on the outer shelf edge, the dispersal limit has not yet been reached.

Palynological provinces

It is possible to distinguish palynological provinces on the basis of the source areas and transport and distribution patterns of pollen. These provinces, which have a certain resemblance to mineral provinces as distinguished in sedimentary petrology, would then be characterized by depositional associations of specific pollen types.

Thus, in the delta region, which forms one large tract characterized mainly by the confluence of source and sedimentation areas, it is possible to differentiate between the levee province and the back-swamp province in that the deposits of the former carry additionally reworked pollen and pollen derived from the upstream drainage basin. In the back-swamp province, a large number of sub-provinces can be distinguished, which reflect the mosaic-like distribution of plant communities in relation to sediment supply.

The offshore provinces are generally characterized by a uniformly mixed supply. Opposite the eastern Orinoco estuaries, the eastern Orinoco shelf provinces can be distinguished. Here, supply from the forested eastern delta is dominant. An inner belt, with higher total pollen content, and an outer belt, with lower total pollen content and progressive sorting effects, can be separated. East of Trinidad, the supply of reworked Pleistocene material, coupled with a very low content of delta pollen, indicates

another province. Airborne supply is absent over the eastern shelf.

In the Gulf of Paria, conditions are more complex, and more provinces can be recognized in this smaller area than on the eastern shelf. Although insufficient data preclude the delineation of provincial boundaries on a quantitative basis, a provisional subdivision can be made, as follows:

The western Gulf province is characterized by a high total-pollen content, with a predominantly local supply from the extensive mangrove belts along the estuaries and shores. The central Gulf province is characterized by a rather high total-pollen content and waterborne supply mainly from the Boca Vagre and Caño Macareo. The eastern Gulf province is a typically mixed one because of waterborne supply through the Serpent's Mouth, causing low total pollen content together with a qualitatively important airborne supply from Trinidad *(Anacardium)*. On the northern shelf, a *Podocarpus-Hemitelia* province can be recognized, characterized by a notable windblown supply from the mountains of Trinidad and Tobago.

Facies recognition

The data on the distribution of pollen and other microfossil groups can also be utilized in studies of depositional environment, and therefore are valuable in facies recognition and in the paleogeographic reconstruction of ancient sedimentary basins. The recognition of palynological provinces makes it possible to distinguish rather sharply the characteristics of each of several major types of depositional environment. The data on the distribution of microfossils originating from the delta, such as cuticles, fungi, and reworked tracheids, on the one hand, and on the distribution of the planktonic Hystrichosphaeridae on the other, add information on the location of estuaries and on salinity. The significance of the foraminiferal remains described should be evaluated in connection with conventional micropaleontological studies of the sediments.

The consistent decrease seaward of the total pollen content of the sediments, and the subsequent modifications of this general trend by local differences in transport facilities, further indicate the possibility of reconstructing main sea-current patterns and the positions of large estuaries and of shore lines in general. In this respect, palynology, in conjunction with sedimentological studies, can make a valuable contribution to paleogeographic interpretation. In view of the practical interest in these problems, a more detailed discussion will be given here.

The positions of the coast lines in the area under study is not invariably reflected in the pollen content of the sediments. The steep, rocky coast of the narrow Paria peninsula shows its presence only by a slight concentration of windblown pollen on the northern side. The northwestern and southern Trinidad coasts are more clearly expressed in the pollen concentrations because of the larger source area inland and the more favourable wind direction. The eastern Trinidad coast, on the other hand, is not expressed in the palynological data because of adverse wind directions and the absence of an appreciable river supply.

The positions of the delta coast line and the mouths of the large estuaries in particular are indicated clearly by the increase in total pollen content toward the main pollen sources. In addition, the disappearance in this direction of *Hystrix* and foraminifera, and the increase in cuticle and fungi content, can be used as guides in detecting the location of the littoral zone. The crossing of the delta shore line, which is taken to be at the outer limit of swamp vegetation and which is not expressed by any distinct lithologic change in the sediments, is registered by an abrupt increase in the total pollen content and a shift in percentage ratios toward local dominance, first of the mangrove association, and farther inland of the other swamp associations. Local variations, such as the lower pollen content in the coarser-grained Boca Vagre deposits and on the levees, of course, disturb this general picture to a certain extent. In addition, the situation opposite the northeastern delta shore line between Caño Macareo and Caño Araguao is worth noting. Here, no major estuaries open into the sea, and wind directions are shoreward. Pollen concentrations in the littoral zone here decrease from east to west parallel to the shore line, because of the predominant east-west current. From the foregoing it can be concluded that in making paleogeographic interpretations, the general direction of a delta shore line can sometimes be detected, but that the actual location is difficult to predict.

The interest in the general problem of shore-line detection is indicated by the "Symposium on finding of ancient shore lines," the abstracts of which were published in the Journal of Sedimentary Petrology (vol. 23, pp. 125–128, 1953), as well as by a United States Patent granted in 1954 to W. S. Hoffmeister, of the Carter Oil Company, entitled "Microfossil prospecting for petroleum." In this patent it is claimed that the positions of ancient shore lines can be determined on the basis of total pollen per gram, the ratio of large to small pollen, and the abundance of *Hystrix* and foraminifera. Hoffmeister's methods are evidently based on data that are closely comparable with the evidence obtained by the present study. For example, his figure of 7500 pollen grains per gram of sediment under nearshore conditions corresponds closely to values determined in the Orinoco sediments.

GENERAL CONCLUSIONS AND PRACTICAL APPLICATIONS

The distribution of pollen, spores, and other microfossils in the Recent Orinoco sediments, as discussed in detail in the preceding chapters is shown to be related principally to the locations of source areas and to the transporting air and water currents. In the delta, transport of pollen grains is restricted, and the local swamp flora is dominant in the sediments. Offshore, the pollen is better mixed. Pollen produced by the delta flora is carried seaward with the Orinoco discharge and incorporated in the offshore sediments over a wide area. In most areas it far outnumbers windblown pollen derived from Trinidad, Tobago, and the Paria peninsula. In the process of gradual settling of the pollen load transported by marine currents, some size selection of grains takes place. Waterborne pollen grains compare in settling speed with fine silt particles, and there are similarities in distribution between these particles and pollen. The total pollen content offshore is shown to reflect the hydrographic current pattern.

Pollen grains reworked from older sediments were recognized, and are most abundant in levee deposits in the delta. They are probably derived from Terti-


EXPLANATION OF PLATE 1

1, pollen grain of *Mauritia* sp., × 1000, Sample Mu-326; 2, pollen grain of *Avicennia nitida*, × 1000, Sample Mu-347; 3, pollen grains of *Rhizophora mangle*, Sample Mu-152: a, polar view, × 1000; b, equatorial view, × 1000 (oil immersion); 4, pollen grain of *Anacardium* type, × 1000, Sta. 1013; 5, spore of *Hemitelia* sp., × 1000, Sta. 346; 6, pollen grain of *Podocarpus* sp., × 1000, Sta. 1009; 7, pollen grain of *Symphonia globulifera*, × 1000, Sample Mu-3; 8, pollen grains of *Terminalia* type, Sample Mu-3: a, polar view, × 1000 (oil immersion); b, equatorial view, × 1000; 9, pollen grain of *Alnus* sp., × 1000, Sample Mu-43; 10, fungal spore, × 1000, Sample Mu-70; 11, tracheid, × 250, Sta. 180; 12, hystrichosphaerid, × 700, Sta. 1207; 13, foraminifer, × 650, Sta. 1202.
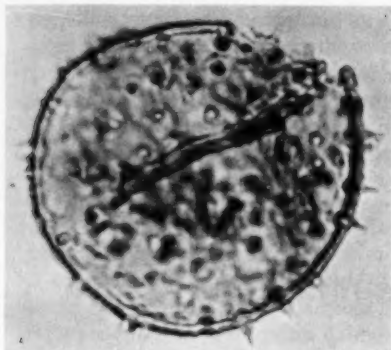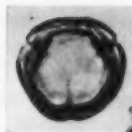
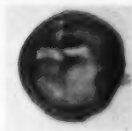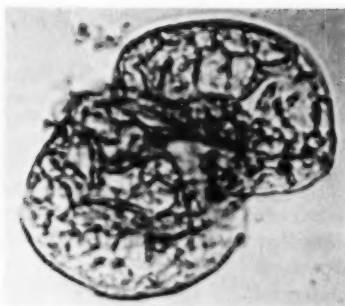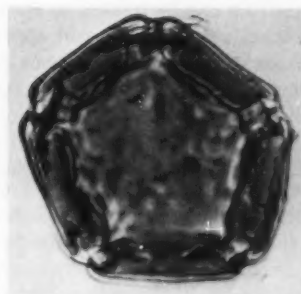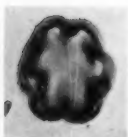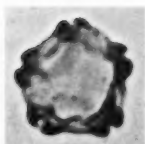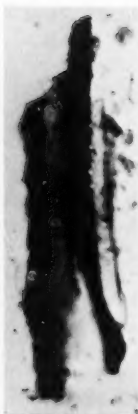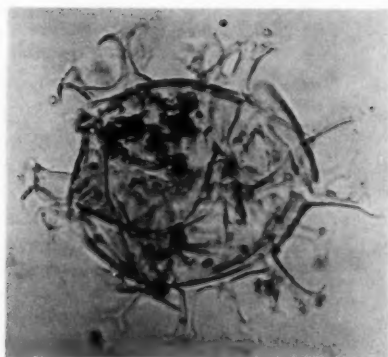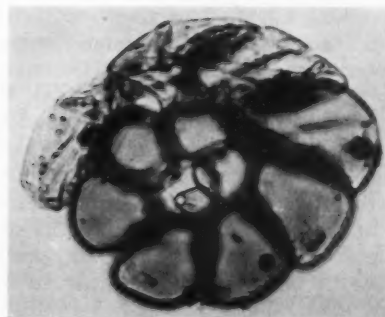ary strata in the Andean foothills, which are being eroded by the Orinoco headwaters. They are also found locally concentrated near outcrops of Tertiary and Pleistocene strata, which are being eroded by wave action.

The distribution of fungal spores, leaf cuticles, and reworked tracheid fragments is mainly restricted to the delta and the littoral belt. The distribution of remains of Hystrichosphaeridae and foraminifera shows the influence of salinity in the offshore area.

These results derived from the surface layer of sediments are supplemented by investigations of three core samples, in which it was found that the microfossil content exhibits variations with depth. These variations can be related to changes in hydrography, sea level, and climate, and appear to have been contemporaneous over the area of investigation. Marked differences from present-day conditions were found only in some of the older Holocene and Pleistocene samples from the eastern shelf area, collected at or below the surface of the sea-floor.

The broader significance of the results obtained lies in their value in refining and perfecting palynology as an aid in geologic exploration. In summary, it can be said that they demonstrate the high potential sensitivity of the palynological method and the degree of integration of this method with sedimentology and paleogeography. The subject of floral change in time could only be touched upon, but the extent to which a detailed palynological study of otherwise homogeneous shale sections might reveal slight but synchronous and causally interrelated changes in climate, sediment supply, and facies is demonstrated in the results of the core investigations.

The results can be applied in the evaluation of local versus regional floral changes and of the reliability of correlation within a single facies province as compared with correlation between different facies provinces within one or more sedimentary basins. This, in practice, will to some degree eliminate empirical procedures in discriminating between regional markers and local ones, especially when working with small-scale quantitative floral changes, and will therefore restrict the number of type-sections that must be examined before reliable zonation can be established. Whenever fossil pollen-types can be identified botanically, the possibility of interpreting paleoecologic change will be increased and it will generally be possible to separate, in a more direct way, the influence of local facies shifts in the pollen diagram from that of regional, climatically controlled changes in vegetation. For example, the fact

that it is possible to recognize *Rhizophora* pollen in the Oligo-Miocene sediments of Venezuela, in combination with the knowledge obtained in the present study of its peculiar distribution pattern, has led to its exclusion from the restricted set of regional zone markers, and at the same time has established this type as a highly useful environmental indicator.

However, it is realized that the results of the present study should not be generalized indiscriminately. Strictly speaking, they apply only to the area of Recent Orinoco sedimentation, and many basins may be found in which different conditions of pollen supply and sedimentation exist and in which the rules formulated above may not hold.

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ABSTRACT: *The duly designated genotype* Spirocyclina choffati *Munier-Chalmas, 1887, from the Senonian of Les Martigues, southern France, has never been figured to date, so that the genus* Spirocyclina *has been repeatedly misinterpreted and is still not definitely known. With regard to its internal organization,* Spirocyclina choffati *from the Senonian of the Marseille region differs from the other forms of "Spirocyclina" of authors recorded from the Upper Jurassic and Lower Cretaceous; the generic name* Iberina *Munier-Chalmas, 1902, is therefore reinstated for the tests described first by Choffat from Portugal and subsequently by numerous authors from many other parts of the Tethys domain.*

The foraminiferal genera Spirocyclina and Iberina

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INTRODUCTION

The homogeneity of the genus *Spirocyclina* Munier-Chalmas, 1887, has been questioned by the writer since 1936, when he identified the first specimens of "*Spirocyclina*" auctorum in the Swiss Alps and then attempted to systematize the data in the scattered and highly controversial literature on the genus (Maync, 1938). It seemed difficult indeed to believe that a species which is abundantly represented in the Upper Jurassic and basal Cretaceous of Portugal and the Tethys province could recur in southern France at a much higher stratigraphic level (Senonian) without having been recorded elsewhere in the Cretaceous. Moreover, since the designated genotype *Spirocyclina choffati* Munier-Chalmas, 1887, from the Senonian of the Marseille area (Les Martigues, Étang de Berre, and Étang de Caronte), had never been figured in the literature, any inference with regard to its identity with the specimens collected by Choffat in Portugal (1885) must obviously be inconclusive.

It became possible to resolve this interesting problem when the writer returned to Europe, where he was able to examine both original collections and ample topotype material. A first-hand study of the two original "types" of *Spirocyclina choffati* in the collection of Munier-Chalmas (Faculté des Sciences, Sorbonne, Paris) was possible, and these specimens are here figured for the first time.

Thanks to the kind efforts of Messrs. Antonio de Castello Branco, Director of the Geological Service of Portugal, and J. M. Pires Soares, of Lisbon, the writer also had an opportunity to study some of the original material collected by Choffat in Portugal. J. Sigal, of the Institut Français du Pétrole, entrusted the writer with a revision of a part of the original collection of Schlumberger (Laboratoire de Géologie, Faculté des Sciences, Sorbonne, Paris), so that additional material collected by Choffat in Portugal could also be evaluated. The Schlumberger collection contains most of the thin sections that were figured in the fundamental paper on *Spirocyclina* (Schlumberger and Choffat, 1904), as well as unfigured material. Moreover, thin sections of the "*Spirocyclina*"-bearing Upper Jurassic material collected by Welsch at Tiaret, Algeria, which has been referred to repeatedly in the literature but has never been figured, are represented in the Schlumberger collection. The Schlumberger collection also contains some specimens of *Spirocyclina choffati* Munier-Chalmas from the Senonian of Les Martigues. Another part of the original collection of Schlumberger, deposited in the collection of H. Douvillé at the École des Mines, Paris, was kindly loaned to the writer for study.

Valuable topotype material from the Kimmeridgian ("Portlandian") of Cape Espichel and other localities in Portugal was kindly placed at the writer's disposal by Dr. H. Hiltermann, of Hannover, to whom cordial thanks are tendered. Pierre Marie, of Paris, provided the writer with some topotype material of *Spirocyclina choffati* from Les Martigues and of "*Spirocyclina choffati* Schlumberger" from Cape Espichel, Portugal. I am profoundly indebted to Pierre Marie for the liberal assistance given me time and again.

Two of the original thin sections of "*Spirocyclina Choffati* var. *euxina* Charles," from Zonguldak, northern Turkey, received years ago from Miss Pfender, were also employed in this study. These specimens were figured by Charles (1933, pl. 27, figs. 4, 7).

Additional material was given me from Portugal by J. M. Pires Soares; from Repiste, Yugoslavia, by the late C. A. Wicher, of Hannover; from Santander, Spain, by P. Rat, of Dijon; from Mallorca Island, Spain, by G. Colom; from Algeria by J. Magné (S. N. REPAL, Algiers) and R. Lacassagne (C.F.P.); and from Tunisia by C. Glintzboeckel (S.E.R.E.P.T., Tunis). Furthermore, all material from wells drilled by the C.E.P. in the Paris basin; thin sections from the Upper Jurassic limestones drilled by ESSO REP (Bègles-Bordeaux) in the Parentis oil field in France, which were placed at my disposal by that Company; a hard-rock sample from Mt. Salève, Haute-Savoie, France, received from the Museum of Natural History at Basel; and one specimen from Barreiro well no. 1, drilled by Mobil Exploration Portugal Inc. near Lisbon, sent me by the Exploration Department of that Company, are included in this study.

Topotype specimens of "*Anchispirocyclina henbesti* Jordan and Applin," from Cape Hatteras Light well no. 1 in Dare County, North Carolina, U.S.A., were studied thanks to the courtesy of Miss L. Jordan, Mrs. E. R. Applin, and the U. S. Geological Survey, Washington. The material from Cuba was given me years ago by the late Donald W. Gravell and by F. G. Keyzer, of Caracas, Venezuela. Thanks to the kindness of Drs. F. R. S. Henson and A. H. Smout, of the Iraq Petroleum Company, Ltd., I was able to examine some material of "*Spirocyclina* sp." from Dukhan wells no. 2 and no. 3, Qatar Peninsula, Arabia.

To date it has proved impossible to locate any material of "*Dicyclina lusitanica* Choffat" and "*Spirocyclina infravalanginiensis* Choffat," mentioned in the literature from the Upper Jurassic-basal Cretaceous of Kokkoz, Crimean Peninsula, U.S.S.R., forms which have been neither described nor figured (Bertrand, 1897, p. 721; Egger, 1902a, p. 586). However, Professor N. Subbotina, of the Petroleum Institute, Leningrad, is trying to obtain and send me some samples from that interesting locality.

It is with sincere appreciation that I herewith extend my cordial thanks to all the colleagues, institutions, and companies who have placed valuable material at my disposal and have permitted the results obtained to be published. The liberal attitude shown me time and again by the Direction of the Compagnie d'Exploration Pétrolière with regard to my research work is particularly acknowledged.

HISTORICAL REVIEW

In 1885, Choffat, recorded the presence of a foraminifer in the Portlandian of the Cintra Mountains, northwest of Lisbon, Portugal (Choffat, 1885, p. 3), but the form was neither described nor figured, and the name given to it, *Orbiculina infravalanginiensis*, is hence a *nomen nudum*. In the same monograph, Choffat pointed out that *Orbiculina infravalanginiensis* is very close to a larger species that he had collected in the Upper Jurassic of Portugal, at Cape Espichel, which he recorded (as another *nomen nudum*) as *Orbiculina lusitanica* (Choffat, 1885, p. 4). Although the species *Orbiculina lusitanica* was stated to occur widely in the Portlandian ("Freixialin" of Choffat), whereas the form *Orbiculina infravalanginiensis* appeared to be more common in beds of Infravalanginian age, it is clear from this and subsequent papers by Choffat that the two species may be found together in the same levels, e.g., in the Portlandian and Infravalanginian of Algarve, southern Portugal, and in the basal Cretaceous of the Cintra region in western Portugal (Choffat, 1885, 1887, 1901).

A number of specimens of *Orbiculina infravalanginiensis* and *Orbiculina lusitanica* from Portugal (in the Choffat collection) were examined by Munier-Chalmas, who concluded that these Portuguese tests are identical with specimens from the Senonian of the Marseille region, southern France. Originally, Munier-Chalmas had intended to describe these forms under the generic name *Trematocyclina*. However, dropping that *nomen nudum* in 1887, he briefly described the forms from the Senonian rudistid-bearing beds of the Étang de Berre and Étang de Caronte near Les Martigues, in the Marseille area, although without giving any figures (Munier-Chalmas, 1887, pp. xxx–xxxi), under the names *Dicyclina*, *Spirocyclina*, and *Cyclopsina*. *Dicyclina schlumbergeri* Munier-Chalmas, 1887, from the Étang de Berre, was selected as the type species of the first-named genus, and *Spirocyclina choffati* Munier-Chalmas, 1887, from the Senonian of the Étangs de Caronte and Berre, was designated as the genoholotype of *Spirocyclina*. The large-sized discoid tests from Portugal *(Orbiculina lusitanica)* were included in the genus *Dicyclina*, while the small coiled forms *(Orbiculina infravalanginiensis)* were referred to *Spirocyclina* (see Choffat, 1900, p. 4; 1901, p. 112).

In 1890, *Spirocyclina* sp. was recorded by Welsch from an outcrop of Kimmeridgian beds at Tagdempt, about 10 km. west-southwest of Tiaret in Algeria (Welsch, 1890, pp. 39, 82); these specimens,

assigned to *Spirocyclina* by Munier-Chalmas, have never been described nor figured. Some material from the "*Spirocyclina*"-bearing beds of Tiaret was sent by Welsch to Schlumberger, in Paris; the four thin sections present in the Schlumberger collection, some of which are figured for the first time in the present publication, are labeled "*Spirocyclina choffati* Mun.-Ch.''

Dicyclina lusitanica (Choffat) and *Spirocyclina infravalanginiensis* (Choffat) were also identified by Munier-Chalmas from Upper Jurassic or basal Cretaceous marls near Kokkoz, on the Crimean Peninsula. A form nearly identical with or similar to *Spirocyclina infravalanginiensis* is also mentioned by Munier-Chalmas from the Kimmeridgian of Besançon, Franche-Comté, France (Bertrand, 1897, p. 721).

In 1902, Munier-Chalmas arrived at the conclusion that *Dicyclina* could not be maintained as a separate genus, but should be interpreted as the final cyclical stage of the foraminiferal genus *Cuneolina* d'Orbigny. Furthermore, he correctly realized that the large form *Dicyclina lusitanica*, found by Choffat in Portugal, cannot be placed in the taxonomic unit *Dicyclina-Cuneolina* because it lacks, for example, the regular secondary septa that subdivide the annular chambers into rectangular chamberlets (Munier-Chalmas, 1902, pp. 350–351). In order to accommodate the Portuguese form, Munier-Chalmas proposed the new genus *Iberina*, with *Dicyclina lusitanica* (Choffat) as the type species.

In his memoir on the orbitolinids and allied forms, Egger (1902a) presented the first description and figures of *Dicyclina lusitanica*, from the Portlandian of Cape Espichel, Portugal, on the basis of specimens received from Choffat. On this account, Egger is the author of the species (Egger, 1902a, pp. 585–586, pl. 6, figs. 3–5). This form was compared with *Dicyclina* (= *Orbitopsella*) *praecursor* (Gümbel), from the Liassic, but no clearcut differentiation was given. Moreover, Egger also published the first description and illustrations of "*Spirocyclina infravalenginiensis*" [*sic*] from Portugal, and is hence also the taxonomic author of that specific name, which was originally proposed in 1885 by Choffat (Egger, 1902a, p. 586, etc., pls. 3–6, *partim*). Furthermore, Egger had at his disposal some material from Kokkoz, Crimea, which he reported as containing both *Dicyclina lusitanica* and *Spirocyclina* "*infravalenginiensis*" (loc. cit., p. 595).

The misspelling "*infravalenginiensis*" consistently used by Egger cannot be accepted. Desor's type locality is Valangin, northwest of Neuchâtel, on which

account the internationally used term Valanginian (or Valanginien) is etymologically correct. Moreover, Egger based his study on Choffat's original material from Portugal, which was correctly labeled "*Spirocyclina infravalanginiensis* Munier-Chalmas und Schlumberger" (Egger, 1902a, p. 586). Choffat himself used the proper spelling "*infravalanginiensis*" exclusively (Choffat, 1885, 1887, 1900, 1901).

Egger concluded that *Spirocyclina infravalanginiensis* should be aligned with *Meandropsina vidali*, described from the Senonian of Trago di Noguera in Catalonia Spain (Schlumberger, 1898, 1899). Moreover, the strongly trochoid-trochamminid genus *Dictyopsella* Munier-Chalmas, discovered in the Senonian of Étang de Berre near Marseille and described and figured by Schlumberger from Trago di Noguera, was believed by Egger to represent the juvenile stage of *Meandropsina vidali* Schlumberger (loc. cit.). It is thus obvious that the species *Meandropsina vidali* as interpreted by Egger is a very heterogeneous taxonomic unit, which even includes different genera. Since the external views of the figured specimens clearly depict different forms, and the reproduced median sections show that the cyclical chambers are regularly subdivided into chamberlets (cellules) by radial partitions, we arrive at the conclusion that the drawings in Egger's publication are somewhat schematic and probably do not all illustrate specimens of *Spirocyclina infravalanginiensis* from Portugal. According to Schlumberger and Choffat, Egger's study was based on *Dicyclina* from Portugal as well as on *Spirocyclina*, *Dictyopsella*, and *Meandropsina*. These authors also question whether or not the available material in the Museum at Munich had been reliably labeled (Schlumberger and Choffat, 1904, p. 359). Egger himself admitted that he had included in his study similar species of foraminifera of Jurassic and Cretaceous age which were available in the State collections (Egger, 1902a, p. 577). Since Egger's collection in Munich was destroyed in a bombardment during the Second World War, it is impossible to restudy the figured specimens and to check their provenience. Because of these doubts as to the origin of the described and figured specimens, the memoir by Egger, unfortunately, cannot serve as a reliable source upon which future studies could be based. In a brief supplementary note, Egger pointed out that Schlumberger had refuted the identification of *Spirocyclina infravalanginiensis* from Charneca (Portugal) as *Meandropsina vidali;* the assignment to the genus *Spirocyclina* Munier-Chalmas is now accepted (Egger, 1902b, p. 673).

In 1904, Schlumberger and Choffat published the first fundamental paper on the Portuguese specimens

of *Spirocyclina* and gave authentic figures of the tests collected by Choffat from the Portlandian of Cape Espichel and from the Infravalanginian of Charneca, Sabugo, and Fort du Guincho (Schlumberger and Choffat, 1904, pls. 9–10). These authors supported the conclusion of Munier-Chalmas (1902) that the true *Dicyclina* is not represented at all in the material from Portugal, and they held the view that *Dicyclina lusitanica* (= *Iberina* Munier-Chalmas, 1902) represents nothing but the adult stage of the smaller forms hitherto called *Spirocyclina* (loc. cit., p. 359). After a comparative study of specimens from Portugal, southern France, and Tiaret, Algeria, Schlumberger furthermore concluded (in opposition to the viewpoint held by Munier-Chalmas) that there exist no morphological differences between these forms except the dimensions, on which account he included them all in the species *Spirocyclina choffati* Munier-Chalmas (Schlumberger and Choffat, 1904, p. 362). Because of the fact that the larger discoid form (previously called *Dicyclina lusitanica*) occurs mainly in the Portlandian, however, Schlumberger reduced the former specific names *lusitanica* and *infravalanginiensis* to varietal rank, and distinguished *Spirocyclina choffati* var. *lusitanica* (found predominantly in the Upper Jurassic) from *Spirocyclina choffati* var. *infravalanginiensis*, which is believed to be largely restricted to the Infravalanginian except in Algarve (loc. cit., p. 367). The status quo in 1904 was thus: Not only were the names *lusitanica* and *infravalanginiensis* suppressed as specific designations, but the characteristic forms from Portugal had even lost a generic denomination of their own.

There is no doubt that Schlumberger was in error in assigning the Portuguese specimens to *Spirocyclina choffati* Munier-Chalmas. Although the latter species, being the legally designated genotype of *Spirocyclina*, had never been figured, Schlumberger had access to the collections of Munier-Chalmas; a slide labeled "*Spirocyclina Choffati* (M.-Ch.) (type); Crétacé sup. (Sénonien) Martigues," and thin section no. P. 680, "*Spirocyclina Choffati* M.-Ch., Sénonien, Martigues ST," dated 1887, are present in the Schlumberger collection in Paris. Thin sections reveal that the foraminifera from Portugal differ from the Senonian species of *Spirocyclina*, and that the structural differences are great enough to warrant not only specific but even generic separation (Maync, 1938, 1952, 1956, 1958a).

Spirocyclina erratica, found in the Infravalanginian of Mt. Salève, Haute-Savoie, France, was described in 1913 (Joukowsky and Favre, 1913, pp. 491–492, text-fig. 56, pl. 34, figs. 10–13). That the large, coarsely arenaceous test of this foraminifer cannot be referred to the genus *Spirocyclina* Munier-Chalmas was recently pointed out by the writer, who established the new genus *Ammocycloloculina*, with *Spirocyclina erratica* Joukowsky and Favre as the type species (Maync, 1958c).

A variety of *Spirocyclina choffati* of Schlumberger and Choffat (non Munier-Chalmas) was described and figured from the Upper Jurassic of Zonguldak, northern Turkey, as "*Spirocyclina Choffati* Munier-Chalmas var. *euxina* nov. var." (Charles, 1932, 1933). This variety or geographic race, based on thin sections, shows the same principal features as the large form known from Portugal, but slight differences induced Charles to establish a new variety.

During his investigations on the Upper Jurassic-Cretaceous boundary in the autochthonous Swiss Alps, the author happened to find specimens of the foraminiferal genera *Pseudocyclammina*, *Choffatella*, and "*Spirocyclina*" *auctorum* for the first time in the Alpine domain (Leupold and Maync, 1935; Maync, 1938, p. 57, etc., pl. 4). He proposed to differentiate the Jurassic-Lower Cretaceous specimens from Portugal from the Senonian genotype *Spirocyclina choffati* Munier-Chalmas, and the names *lusitanica* and *infravalanginiensis* were again given specific rank (Maync, 1938, p. 63), an interpretation which has since been generally adopted (Henson, 1948; Rat, 1955; Aurouze and Bizon, 1955).

Most recently, in a paper published by Jordan and Applin, the new genus *Anchispirocyclina* was established, with *A. henbesti* as genotype (Jordan and Applin, 1952, pp. 3–5, pl. 2, figs, 1–4; pl. 3, figs. 1–3). This form was discovered in well samples of probable Portlandian age in North Carolina. It differs from *Spirocyclina* in lacking the reniform or annular adult stage. With regard to its coarsely arenaceous texture, *A. henbesti* differs from the thin-sectioned specimens figured by Schlumberger and Choffat (1904, pls. 9–10), but the large amount of incorporated quartz grains is merely due to ecologic factors, and many of the specimens examined by the writer from France, Spain, Algeria, and elsewhere exhibit a similar predominance of detrital material. As to size and interior structure, *Anchispirocyclina henbesti* cannot be distinguished from "*Spirocyclina*" *infravalanginiensis*, and hence has been placed in synonymy with the latter (Maync, 1956).

The following species and subspecies of *Spirocyclina* and "*Spirocyclina*" *auctorum* have been established:

Spirocyclina choffati Munier-Chalmas, 1887, from the Senonian of Les Martigues in the Marseille area, France;

Dicyclina lusitanica (Choffat) Egger, 1902 = *Spirocyclina choffati* Schlumberger and Choffat (non Munier-Chalmas, 1902) var. *lusitanica* = *Spirocyclina lusitanica* auct.; Portlandian and Infravalanginian of Portugal;

Spirocyclina infravalanginiensis (Choffat) Egger, 1902 = *Spirocyclina choffati* Schlumberger and Choffat (non Munier-Chalmas, 1902) var. *infravalanginiensis* = *Spirocyclina infravalanginiensis* auct.; Portlandian and Infravalanginian of Portugal, Algeria, etc.;

Spirocyclina choffati var. *euxina* Charles, 1933; Portlandian of northern Turkey;

Spirocyclina erratica Joukowsky and Favre, 1913; Infravalanginian of Mt. Salève, Haute-Savoie, France;

Anchispirocyclina henbesti Jordan and Applin, 1952; Portlandian of North Carolina, U.S.A.

The five last-mentioned species all differ from *Spirocyclina choffati* in their interior organization and structure. Since the generic name *Spirocyclina* will be retained for the duly designated, although not figured genotype *Spirocyclina choffati* Munier-Chalmas, the other forms must be removed from that genus.

The two Portuguese forms "*Dicyclina*" *lusitanica* and "*Spirocyclina*" *infravalanginiensis* represent the generations B and A of a single species, which, however, shows a structure different from that of *Spirocyclina choffati*. These forms, which were first made known from Portugal but have since proved to have wide geographic distribution within the Tethys domain (Maync, 1956), are here united in the genus *Iberina* Munier-Chalmas, 1902, and included in the species *Iberina lusitanica* (Egger). "*Spirocyclina*" *choffati euxina* Charles falls within the range of variation of the species *Iberina lusitanica* (Egger).

"*Spirocyclina*" *erratica* Joukowsky and Favre, from the Infravalanginian of Mt. Salève, was recently selected as the type species of the new genus *Ammocycloloculina* Maync, 1958, a genus of arenaceous foraminifera. This species cannot be placed in *Spirocyclina*, *Iberina*, or any other choffatelline genus because of its interior structure and the absence of a reticulate sub-epidermal layer (Maync, 1958c).

Anchispirocyclina henbesti Jordan and Applin, described from the eastern United States, shows very close agreement with "*Spirocyclina*" *infravalanginiensis* with respect to size and interior structure, and has therefore been declared a junior synonym of that form (Maync, 1956). It is now included in the species *Iberina lusitanica* (Egger).

The Bathonian form *Spirocyclina casterasi* Bonte, 1941, which was not figured until 1944, was subsequently placed in synonymy with *Orbitammina elliptica* (d'Archiac) by its author (Bonte, 1941, 1944). This foraminifer has nothing to do with either *Spirocyclina* or *Iberina*, as it lacks the sub-epidermal alveolar layer.

Coskinolinopsis primaevus Henson, 1948, was recently assigned to the genus *Spirocyclina* by Oberhauser (Blumenthal, 1956, p. 23). This taxonomic change is not justified, however, since the species as interpreted by its author exhibits a conical-flabelliform test showing a uniserial adult stage and narrow chambers subdivided by pillars and interseptal partitions (Henson, 1948). The presence of a peripheral zone formed by coarse vertical partitions and a central shield pierced by numerous apertures suggests that *Coskinolinopsis primaevus* is a primitive orbitolinid foraminifer, whereas *Spirocyclina* and *Iberina* show an entirely different organization.

SYSTEMATICS

Our recent investigations have indicated that there exist morphological differences within the collective group "*Spirocyclina*." Consequently, this heterogeneous group is now divided into two different genera, *Spirocyclina* and *Iberina*.

<div align="center">

Order FORAMINIFERA

Superfamily LITUOLIDEA

Family LITUOLIDAE

Subfamily CHOFFATELLINAE

Genus **Spirocyclina** Munier-Chalmas, 1887, **emend.** Maync

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The genus *Spirocyclina* as conceived by its author (Munier-Chalmas, 1887, p. xxxi), not as it was subsequently interpreted by Schlumberger and Choffat (1904), is virtually unknown because its genoholotype (*Spirocyclina choffati* Munier-Chalmas, 1887) has never yet been figured. Munier-Chalmas also failed to select a holotype for the type species, so that the nature of the genus *Spirocyclina* Munier-Chalmas still remains vague and controversial.

A lectotype and a paratype are here selected from the two well-preserved isolated tests indicated by Munier-Chalmas himself as representing the "types" (slide in his original collection). These specimens come from the Senonian of Étang de Berre, near Les Martigues in the Marseille region, southern France, and are deposited in the collection of E. Munier-Chalmas, Faculté des Sciences, Laboratoire de Géologie, Sorbonne, Paris.

Pierre Marie has recently also studied the genus. He has not only examined the specimens represented in the Munier-Chalmas collection, but also collected topotype material of *Spirocyclina choffati*. The liberal and disinterested co-operation on the part of Pierre Marie has been invaluable in my studies, and his support is here very gratefully acknowledged. Marie based his study on the external characters of the test, whereas I have placed the most weight on its internal structure.

The original description of the genus *Spirocyclina* is quoted below:

"Test s'enroulant en décrivant une spire plane. Ouvertures placées vers la partie supérieure de la spire. Une grande partie des autres caractères présentent la même disposition générale que dans les *Dicyclina*.

"Hab. – Cénomanien, Turonien, Sénonien, faciès à Rudistes. "Type. – *Spirocyclina Choffati*, Mun.-Ch., 1887. Accompagne *Cyclopsina Steinmanni*.

"M. Choffat a retrouvé dans les couches infra-valanginiennes du Portugal les genres *Dicyclina* et *Spirocyclina*. Le réseau particulier, qui se retrouve dans les quatre genres suivants: *Orbitolina (Patellina)*, *Dicyclina*, *Spirocyclina* et *Cuneolina*, d'Orb., montre qu'ils peuvent constituer une famille que M. Munier-Chalmas désigne sous le nom de *Spirocyclinidae*" (Munier-Chalmas, 1887, p. xxxi).

As for *Dicyclina* Munier-Chalmas, 1887, to which reference is made in the quotation given above, Munier-Chalmas gave the following description:

"Test discoïdal mince, présentant sur *ses deux faces* un réseau caractéristique formé de mailles arrondies ou carrées, à parois minces, destinées à établir la communication avec l'intérieur des loges. Loges principales subdivisées très régulièrement en loges secondaires par des cloisons rayonnantes et équidistantes, et disposées concentriquement sur deux plans parallèles pour former deux cycles distincts de loges opposées. Plusieurs rangs de mailles régulières placées sur le pourtour du disque et correspondant aux ouvertures.

"Habit. – Cénomanien, Turonien, Sénonien, faciès à Rudistes.

"Type. – *Dicyclina Schlumbergeri*, Mun.-Ch., 1887. Espèce de très grande taille atteignant 30 à 35 mm.

"Couches moyennes à *Hippurites* de l'Étang de Berre" (Munier-Chalmas, 1887, pp. xxx–xxxi).

As may be seen, the original description of the genus *Spirocyclina* is by no means conclusive, and it is not clear which of the morphologic features ascribed above to *Dicyclina* are regarded as characterizing the genus *Spirocyclina* as well. A new diagnosis and description are therefore given here:

Emended diagnosis: A peneroplid to *Choffatella*-like form provided with multiple apertures which are usually aligned in two linear series parallel to the plane of coiling. With respect to its internal structure, *Spirocyclina* differs from *Choffatella*, *Pseudocyclammina*, and *Iberina* in the presence of a zone of radial transverse partitions (beneath the alveolar sub-epidermal layer), which form rectangular secondary chamberlets. Toward

the central portion of the test, these interseptal partitions are reduced to regular projections of the inter-apertural segments of the septa which reach inward into the lumina. Only one (rarely more) of these elongated projections in the equatorial plane may reach the opposite (previous) septum, so that the open chambers are sometimes discontinued in the very center of the test. In other words, a continuous median closure occasionally divides one half of the test from the other. This median septal partition also manifests itself in the double row of apertural openings on either side of the central plane.

Known from the Upper Cretaceous only.

Spirocyclina choffati Munier-Chalmas, emend. Maync
Plate 1, figures 1–10

Spirocyclina choffati Munier-Chalmas, 1887, Soc. Géol. France, C. R. Somm., no. 7, 21 Février 1887, p. xxxi (not figured).
Not *Spirocyclina choffati* Munier-Chalmas. – Schlumberger and Choffat, 1904, and later authors.

Lectotype: *Spirocyclina choffati* Munier-Chalmas, 1887; one of the two original specimens deposited in Paris (Faculté des Sciences, Laboratoire de Géologie, Sorbonne), which Munier-Chalmas himself designated as "types" (pl. 1, fig. 1, 1a, 1b).

Note: A foraminiferal slide labeled "*Spirocyclina choffati* (M.-Ch.) (type), Crétacé Sup. (Sénonien), Martigues" is deposited in the Schlumberger collection in Paris. This modern slide contains one specimen of *Spirocyclina choffati* and has arbitrarily been selected as the type by some unknown recent worker, whereas the tests in the collection of Munier-Chalmas were duly designated as types by the author of the genus and species.

Paratype: Second specimen labeled as "type" in the collection of Munier-Chalmas (pl. 1, fig. 2, 2a).

Hypotypes: Specimens in the collections of P. Marie and C. Schlumberger, Paris (pl. 1, figs. 3–10).

Locus typicus: Étangs de Berre and Caronte, Les Martigues, near Marseille, southern France.

Stratum typicum: Senonian rudistid beds.

Description: Test large, planispirally coiled but often somewhat deformed and occasionally (particularly in the last-formed chamber) deviating slightly from the original plane of coiling, as in *Choffatella* and *Pseudocyclammina*. Spire similar to that of *Choffatella* (form B) but not quite involute (part of the inner convolutions visible) and opening rapidly in a flaring peneropline mode; occasionally the latest chambers may become detached (uncoiling). Periphery subacute but apertural face flattened and bordered by rather sharp edges. Aperture consisting of multiple openings aligned in two parallel vertical series on the apertural face (pl. 1, fig. 3). Chambers narrow and strongly recurved as in *Iberina*,

about twenty-five or more in the last whorl. Sutures clearly visible on the surface of the test.

Diameter of lectotype (pl. 1, fig. 1, 1a, 1b) 3.88 mm.; thickness at the center 0.31 mm.; breadth of the last-formed chamber 0.54 mm. Diameter of paratype (pl. 1, fig. 2, 2a) 3.82 mm.; thickness 0.31 mm. (center) and 0.56 mm. (across apertural face). The hypotypes vary in diameter from 1.82 mm. to 4.58 mm. (average 2.95 mm.), with axial diameters of 0.22–0.45 mm. (center) and 0.38–0.58 mm. (apertural face), respectively.

Internal structure: Worn tests and thin sections reveal that the imperforate epidermis is underlain by a relatively coarse alveolar layer with meshes about 20 microns in size. Below this sub-epidermal structure follows a zone in which the recurved chambers are separated from each other by compact septa (slightly thinner than the width of the lumina). The arcuate chambers of this zone are subdivided into regular chamberlets by radial, evenly spaced secondary septula (eight to ten per millimeter along the septum). In the subjacent central portion of the test the septa are observed to have fairly regularly spaced apertural perforations, about eight to ten per millimeter measured along the septum (there are twice as many or more in the genera *Choffatella* and *Iberina* and in some species of *Pseudocyclammina*). These apertural passages are in alignment from one septum to the following. Oblique sections indicate that the sub-epidermal alveoles are connected with the secondary chamberlets of the intermediate zone and farther inward with the apertural passages piercing each septum: Two or three of the near-surface cells, corresponding with tubular passages toward the interior, converge inwardly and lead to the secondary chamberlets, from which the passage continues into one of the apertural intra-septal perforations (pl. 1, fig. 10).

In this inner zone, characterized largely by open chambers, the secondary radial septula are reduced to regular processes which project from the inner side of each septal segment (between the apertural passages) into the preceding chamber but generally fail to reach the opposite side of the chamber or the next inner septum, so that, as a rule, communication within each lumen is maintained. However, one of the projections in the median plane is often continuous, so that the test is then traversed by an equatorial bar. In other tests the interior chambers show a subdivision by two partitions that develop from the regular interseptal projections. In any case, the innermost zone of the test of *Spirocyclina* consists largely of more or less open chambers. The Upper Jurassic-basal Cretaceous genus *Iberina*, however, which was formerly considered to be identical with *Spirocyclina choffati*, shows a zone of open *Choffatella*-like chambers beneath the reticulate sub-epidermal layer. Its central portion consists of a labyrinthic structure that tends to obliterate the original chambers, leaving the characteristic irregular network formed by the interseptal passages and the remnants of the lumina. *Spirocyclina* thus reveals a different internal organization, on account of which the genus *Iberina* is here re-instated.
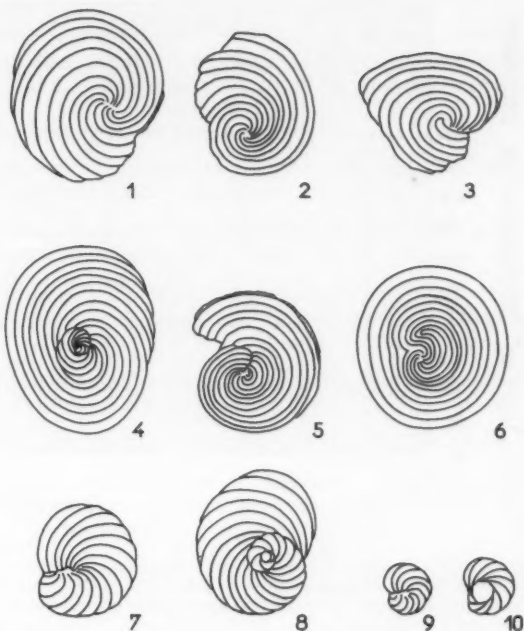
TEXT-FIGURE 1

Schematic diagram showing morphology and mode of coiling in the tests of *Iberina lusitanica* (Egger), emend. Maync: 1–6, generation B; 7–8, generation A-1; 9–10, generation A-2 (the initial coil shown in figs. 4, 8 and 10 as seen in sections).

There were not enough tests of *Spirocyclina choffati* available to prepare a large number of thin sections. It is therefore not possible to make any comments on the differences between the forms A and B. The former are, however, clearly recognizable by their considerably smaller size and larger proloculus (pl. 1, fig. 5).

To date, *Spirocyclina choffati* Munier-Chalmas is the only known species of the genus *Spirocyclina*.

Genus **Iberina** Munier-Chalmas, 1902, **emend.** Maync

Orbiculina Lamarck. – Choffat, 1885.
*Trematocyclina* Munier-Chalmas, 1885 *(nomen nudum)*.
Dicyclina Munier-Chalmas, 1887 (part).
Spirocyclina Munier-Chalmas, 1887 (part).
Meandropsina Schlumberger. – Egger, 1902.
Dicyclina Munier-Chalmas of authors (in part): Choffat, 1887; Bertrand, 1897; Choffat, 1900, 1901; Egger, 1902; Choffat, 1904.
Spirocyclina Munier-Chalmas of authors: Choffat, 1887; Welsch, 1890; Bertrand, 1897; Choffat, 1900, 1901; Egger, 1902; Choffat, 1904; Schlumberger and Choffat, 1904; Charles, 1932, 1933; Maync, 1938; Lucas, 1942; Bonte, 1944; Henson, 1948; Dalloni, 1952; Maync, 1952; Rat, 1955; Aurouze and Bizon, 1955; Zbyszewski, 1955; Zbyszewski and d'Almeida, 1955; Emberger and Magné, 1955, 1956; Dalbiez and Séronie-Vivien, 1957.
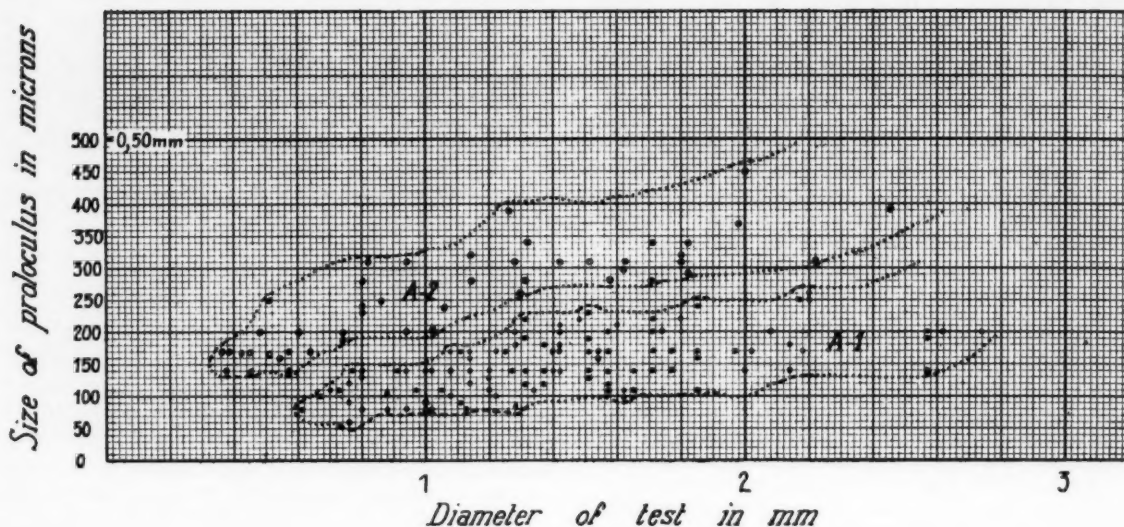
TEXT-FIGURE 2

Iberina lusitanica (Egger), emend. Maync, diagram showing variability in the two megalospheric generations A-1 (●) and A-2 (○) (maximal diameter of test plotted against size of proloculus).

Not *Spirocyclina* Munier-Chalmas. – JOUKOWSKY AND FAVRE, 1913.
Peneroplis Montfort. – SOUSA TORRES AND PIRES SOARES, 1946 (part).
Not *Spirocyclina* Munier-Chalmas. – COLOM, 1947.
Anchispirocyclina JORDAN AND APPLIN, 1952.
Choffatella Schlumberger. – SIGAL, 1952 (part).
"*Spirocyclina*" MAYNC, 1956, 1958.

In 1902, Munier-Chalmas discussed various foraminifera that are provided with a polygonal meshwork (sub-epidermal alveolar layer), among which only the genera *Dicyclina* and *Spirocyclina* have a bearing on the present study. The original description of *Dicyclina* given by Munier-Chalmas is quoted below:

"Le genre *Dicyclina* M.-Ch., représenté dans le Sénonien des Martigues par *D. Schlumbergeri*, correspond à une phase cycloïdale des *Cunéolina* d'Orb. Son plasmostracum est formé de demi-loges circulaires qui se développent alternativement de chaque côté du disque, comme celles des Cunéolines (*accroissement dichrone*). Le réseau de mailles polygonales recouvre directement les parois des loges circulaires et les cloisons qui les divisent si régulièrement en compartiments rectangulaires.

"M. Choffat a désigné, après m'avoir consulté, sous le nom de *Dicyclina Lusitanica*, un Foraminifère nouveau qu'il avait découvert dans le Portlandien du Portugal, lors de ses belles explorations stratigraphiques. J'avais pensé à cette époque que l'espèce de M. Choffat, par suite de la présence du réseau de mailles polygonales, devait être rapportée au genre *Dicyclina*. Aujourd'hui, par suite de considérations d'un autre ordre, je pense que l'espèce décrite par M. Choffat doit devenir le type du genre *Iberina*. Le plasmostracum discoïdal s'accroît péri-phériquement en un seul temps, au moment de la formation de

chaque nouvelle loge circulaire, comme celui des *Orbitolites* (*accroissement monochrone*). Le réseau de mailles polygonales qui se divise en deux zones (une zone externe à mailles très fines, et une zone interne à mailles plus larges) repose directement sur les parois des loges circulaires et recouvre les canaux circulaires à sections obliques et inclinées, qui, dans toute loge, se présentent au nombre de deux, placés respectivement de chaque côté du disque. Les cloisons qui, dans les *Dicyclina*, divisent si régulièrement les loges en compartiments rectangu-laires, n'existent pas dans les *Iberina*" (Munier-Chalmas, 1902, pp. 350–351).

It was thus indicated that the specimens of *Dicyclina* from the Senonian of the Marseille area actually represent the final cyclical phase of the genus *Cuneolina* d'Orbigny, 1839, and that the assignment of *Dicyclina lusitanica* from the Portlandian and Infravalanginian of Portugal to that genus is incorrect. This conclusion was reached mainly because of the fact that a double layer of annular chambers is developed in *Dicyclina* which was not observed in the Portuguese form. Another basic difference was seen in the fact that the chambers in "*Dicyclina*" *lusitanica* are not subdivided into rectangular chamberlets by interseptal partitions, a feature which is, however, characteristic of the genus *Dicyclina-Cuneolina* (Munier-Chalmas, loc. cit.).

Although Munier-Chalmas did not accompany his description of the genus by a figure, he stated un-mistakably ("*intentio auctoris*") that *Iberina* is based on *Dicyclina lusitanica* from the Portlandian of Portugal (Munier-Chalmas, 1902, p. 350). This form had been figured a very short time previously by Egger (1902a, pl. 6, figs. 3–5).

Transverse sections showing the diagnostic labyrinthic growth in the central portion of the chambers in *Iberina* (a–d); in *Pseudocyclammina* (e–g) and in *Choffatella* (h–k), the lumina are open. All figures × 18. (Text-figures 3h and 3i after Maync, 1950, pl. 11, figs. 8, 12.)

Emended diagnosis: A genus of lituolid-choffatelline foraminifera of variable shape (choffatelloid, peneroplid, reniform-cyclical), with a cribrate aperture. Chambers narrow, arcuate, and strongly embracing, in the microspheric generation sometimes reniform and ultimately annular. Septa choffatelloid (pierced by numerous apertural channels). A zone of undivided chambers beneath the alveolar sub-epidermal layer (*Choffatella* stage) is typical. The subcentral and central zones are characterized by interseptal, often lamelliform projections and pillars wich develop from the septal segments (between the apertural perforations) inward into the preceding chambers, forming an irregular pattern by interfusion with each other and with the septal walls. In this manner, the lumina of the subcentral and central zones become intricately subdivided, and this diagnostic labyrinthic growth differentiates *Iberina* from *Spirocyclina* as well as from the genera *Choffatella* and *Pseudocyclammina*.

This monotypic genus is known from the Upper Jurassic (Kimmeridgian) and basal Cretaceous.

Iberina lusitanica (Egger), emend. Maync

Plate 2, figures 1–17; plate 3, figures 1–12; plate 4, figures 1–4; plate 5, figures 1–11; plate 6, figures 1–10; plate 7, figures 1–15; plate 8, figures 1–15; text-figures 1–3

Orbiculina infravalanginiensis CHOFFAT, 1885, Rec. Mon. Strat. Syst. Crét. Port., p. 3, etc. *(nomen nudum).*

Orbiculina lusitanica CHOFFAT, 1885, ibid., p. 4, etc. *(nomen nudum).*

Trematocyclina Munier-Chalmas, 1885. – CHOFFAT, 1885 (part; *nomen nudum*) *(fide* SCHLUMBERGER AND CHOFFAT, 1904, Soc. Géol. France, Bull., ser. 4, vol. 4, p. 364).

Dicyclina sp., MUNIER-CHALMAS, 1887 (part), Soc. Géol. France, C. R. Somm., no. 7, p. xxxi.

Spirocyclina sp., MUNIER-CHALMAS, 1887 (part), ibid., p. xxxi.

Dicyclina lusitanica Choff. *(Orbiculina).* – CHOFFAT, 1887, Rech. Terr. Sec. Sud. Sado, vol. 1, fasc. 2, p. 268, etc. *(nomen nudum).*

Spirocyclina infravalanginiensis Choffat *(Orbiculina).* – CHOFFAT, 1887, ibid., p. 273, etc. *(nomen nudum).*

Spirocyclina Munier-Chalmas sp. – WELSCH, 1890, Terr. Sec. env. Tiaret, Alg. (Thèse Fac. Sci. Paris, Lille), pp. 39, 82.

Dicyclina lusitanica Choffat. – BERTRAND, 1897, Soc. Géol. France, Bull., ser. 3, vol. 25, no. 7, p. 721 *(nomen nudum).*

Spirocyclina infravalanginiensis Choffat. – BERTRAND, 1897, ibid., p. 721 *(nomen nudum).*

Spirocyclina infravalanginiensis Choffat. – CHOFFAT, 1900, Rec. Mon. Strat. Syst. Crét. Port.; 2e étude, Crét. sup. Nord Tage, p. 4 *(nomen nudum).*

Dicyclina lusitanica Choffat. – CHOFFAT, 1900, ibid., p. 4 *(nomen nudum).*

Dicyclina lusitanica CHOFFAT, 1901, Soc. Belge Géol., Mém. Bull., vol. 15, p. 121 *(nomen nudum).*

Spirocyclina infravalanginiensis Chof. – CHOFFAT, 1901, ibid., p. 123 *(nomen nudum).*

Dicyclina lusitanica EGGER, 1902, K. Bayer. Akad. Wiss. München, Math.-Phys. Cl., Abh., Cl. 2, vol. 21, pt. 3, pp. 585–586, pl. 6, figs. 3–5.

Spirocyclina infravalenginiensis [*sic*] EGGER, 1902 (part), ibid., pp. 586–591, pls. 3–6.

Meandropsina vidali Schlumberger. – EGGER, 1902, ibid., p. 586, etc., pls. 3–6.

Iberina lusitanica Choffat. – MUNIER-CHALMAS, 1902, Soc. Géol. France, Bull., ser. 4, vol. 2, p. 350.

Spirocyclina choffati Munier-Chalmas. – EGGER, 1902, K. Bayer. Akad. Wiss. München, Math.-Phys. Cl., Abh., Cl. 2, vol. 21, pt. 3, p. 673, etc.

Spirocyclina choffati Munier-Chalmas. – SCHLUMBERGER AND CHOFFAT, 1904, Soc. Géol. France, Bull., ser. 4, vol. 4, no. 3, p. 358, etc., pls. 9–10.

Spirocyclina choffati Munier-Chalmas var. *lusitanica*. – SCHLUM-BERGER AND CHOFFAT, 1904, ibid., p. 367.

Spirocyclina choffati Munier-Chalmas var. *infravalanginiensis*. – SCHLUMBERGER AND CHOFFAT, 1904, ibid., p. 367.

Spirocyclina Munier-Chalmas sp. – CHARLES, 1932, Soc. Géol. Belgique, Proc. Verb., vol. 55, Bull., no. 10, pp. 247–249.

Spirocyclina choffati Munier-Chalmas var. *euxina* CHARLES, 1933, Soc. Géol. France, Bull., ser. 5, vol. 2, no. 5–7, pp. 465–475, pl. 27, figs. 1–7.

Spirocyclina lusitanica (Choffat). – MAYNC, 1938, Eclogae Geol. Helv., vol. 31, no. 1, p. 61.

Spirocyclina infravalanginiensis (Choffat). – MAYNC, 1938, ibid., p. 61, etc., pl. 4, fig. 11.

Spirocyclina choffati Munier-Chalmas var. *infravalanginiensis* Choffat. – LUCAS, 1942, Service Carte Géol. Algérie, Bull., ser. 2 (Strat., Descr. Gén.), no. 16, pp. 387, 396, 402, etc.

Spirocyclina choffati Munier-Chalmas. – BONTE, 1944, Soc. Géol. France, Bull., ser. 5, vol. 12 (1942), pp. 336–342.

Peneroplis aff. *planatus* (Fichtel and Moll) var. *assunçãoi* SOUSA TORRES AND PIRES SOARES, 1946, Portugal, Minist. Col., Mém., Ser. Geol., no. 3 (Form. Sed. Arq. Cabo Verde), vol. 1, pp. 205, 211, pl. 18, fig. 5; pl. 19, figs. 1–3.

?Spirocyclina infravalanginiensis Choffat. – BERNOULLI, 1946 (part), Naturf. Ges. Basel, Verh., vol. 62, pp. 22, 37.

Non *Spirocyclina* (and *Spirociclina*) cf. *infravalanginiensis* Choffat. – COLOM, 1947, Estud. Sed. Prof. Baleares, pp. 75, 76, pl. 14, figs. 1–2.

Spirocyclina Munier-Chalmas sp. – HENSON, 1948, Larger imperf. foram. S.W.-Asia, pp. 19–20, pl. 10, figs. 8(?), 9; pl. 13, figs. 1–2.

Anchispirocyclina henbesti JORDAN AND APPLIN, 1952, Cushman Found. Foram. Res., Contr., vol. 3, pt. 1, pp. 3–5, pl. 2, figs. 1–4; pl. 3, figs. 1–3.

Spirocyclina choffati var. *infravalanginiensis*. – DALLONI, 1952, Congr. Internat. Géol., XIX, Monogr. Rég., ser. 1 (Algérie), no. 24, p. 64.

Choffatella zireggensis SIGAL, 1952, ibid., no. 26, pp. 12–13.

Spirocyclina infravalanginiensis Choffat. – RAT, 1955, Acad. Sci., C. R., vol. 239 (1954), pp. 1820–1821.

Spirocyclina infravalanginiensis. – AUROUZE AND BIZON, 1955, Soc. Géol. France, Bull., ser. 6, vol. 5, pp. 51–54, pl. 1b, figs. 1–6.

Spirocyclina choffati Munier-Chalmas var. *infravalanginiensis* Choffat. – ZBYSZEWSKI, 1955, Portugal, Serv. Geol., Not. Explic. Carta Geol. Arred. Lisboa, p. 26.

Spirocyclina choffati Munier-Chalmas var. *lusitanica* Choffat. – ZBYSZEWSKI, 1955, ibid., p. 27.

Spirocyclina choffati Munier-Chalmas var. *lusitanica* Choffat. – ZBYSZEWSKI AND D'ALMEIDA, 1955, Portugal, Serv. Géol., Not. Explic. Carta Geol. Port., Folha Torres Vedras, p. 16.

Spirocyclina choffati Munier-Chalmas. – MAGNÉ, 1955, in EMBERGER, Soc. Géol. France, Bull., ser. 6, vol. 5, fasc. 7–9, pp. 544–545.

Spirocyclina choffati Munier-Chalmas. – EMBERGER AND MAGNÉ, 1956, Soc. Géol. France, C. R. Somm., no. 11, p. 190.

"*Spirocyclina*" *lusitanica* Choffat. – MAYNC, MS., Congr. Geol. Internat., XX (Mexico, 1956), Cretaceous Symposium (in press).

"*Spirocyclina*" *infravalanginiensis* Choffat. – MAYNC, MS., ibid.

Spirocyclina infravalanginiensis Schlumberger. – DALBIEZ AND SÉRONIE-VIVIEN, 1957, Soc. Linnéenne Bordeaux, Proc. Verb., vol. 96, p. 37.

"*Spirocyclina*" *lusitanica*. – MAYNC, 1958, Cushman Found. Foram. Res., Contr., vol. 9, pt. 1, p. 1.

"*Spirocyclina*" *infravalanginiensis*. – MAYNC, 1958, ibid., p. 1.

"*Spirocyclina*" *lusitanica*. – MAYNC, 1958, Cushman Found. Foram. Res., Contr., vol. 9, pt. 3, pp. 53, 55.

"*Spirocyclina*" *infravalanginiensis*. – MAYNC, 1958, ibid., pp. 53, 55.

The species "*Dicyclina (Orbiculina) lusitanica* Choffat," repeatedly cited in the literature (Choffat, 1885, 1887, 1900, 1901; Bertrand, 1897; Munier-Chalmas, 1902), was never figured prior to 1902. Egger, in his memoir on the orbitolinids, was the first to publish a description and figures of this form (1902a, pp. 585–586, pl. 6, figs. 3–5), and the specific name *lusitanica*, proposed by Choffat in 1885, is therefore to be credited to Egger. The species *Dicyclina lusitanica* (Choffat) Egger should be cited as *Iberina lusitanica* (Egger).

However, since the Egger collection in Munich was completely destroyed during the Second World War, the holotype of *Dicyclina lusitanica* Egger = *Iberina lusitanica* (Egger), duly figured and described (Egger, 1902a, loc. cit.), is no longer available. On this account, the generic name *Iberina* must be based on other

PLATE 1

Spirocyclina choffati Munier-Chalmas, emend. Maync, from the Senonian of Les Martigues (Étang de Berre, Étang de Caronte), near Marseille, southern France: 1, lectotype (Munier-Chalmas collection, Paris), × 13.5: 1, 1a, side views; 1b, peripheral view; 2, 2a, paratype (Munier-Chalmas collection, Paris), side views, × 13.5; 3, topotype from Les Martigues (Marie collection, Paris), apertural view, × 27; 4–8, 10, thin-sectioned topotypes from Les Martigues (Marie collection, Paris), showing the internal structure: 4, 8, transverse sections, × 13.5; 5, axial section of a megalospheric test, × 27; 6–7, median sections, × 13.5; 10, oblique section, × 27; 9, thin-sectioned specimen from Étang de Berre (Schlumberger collection, Paris), × 27.
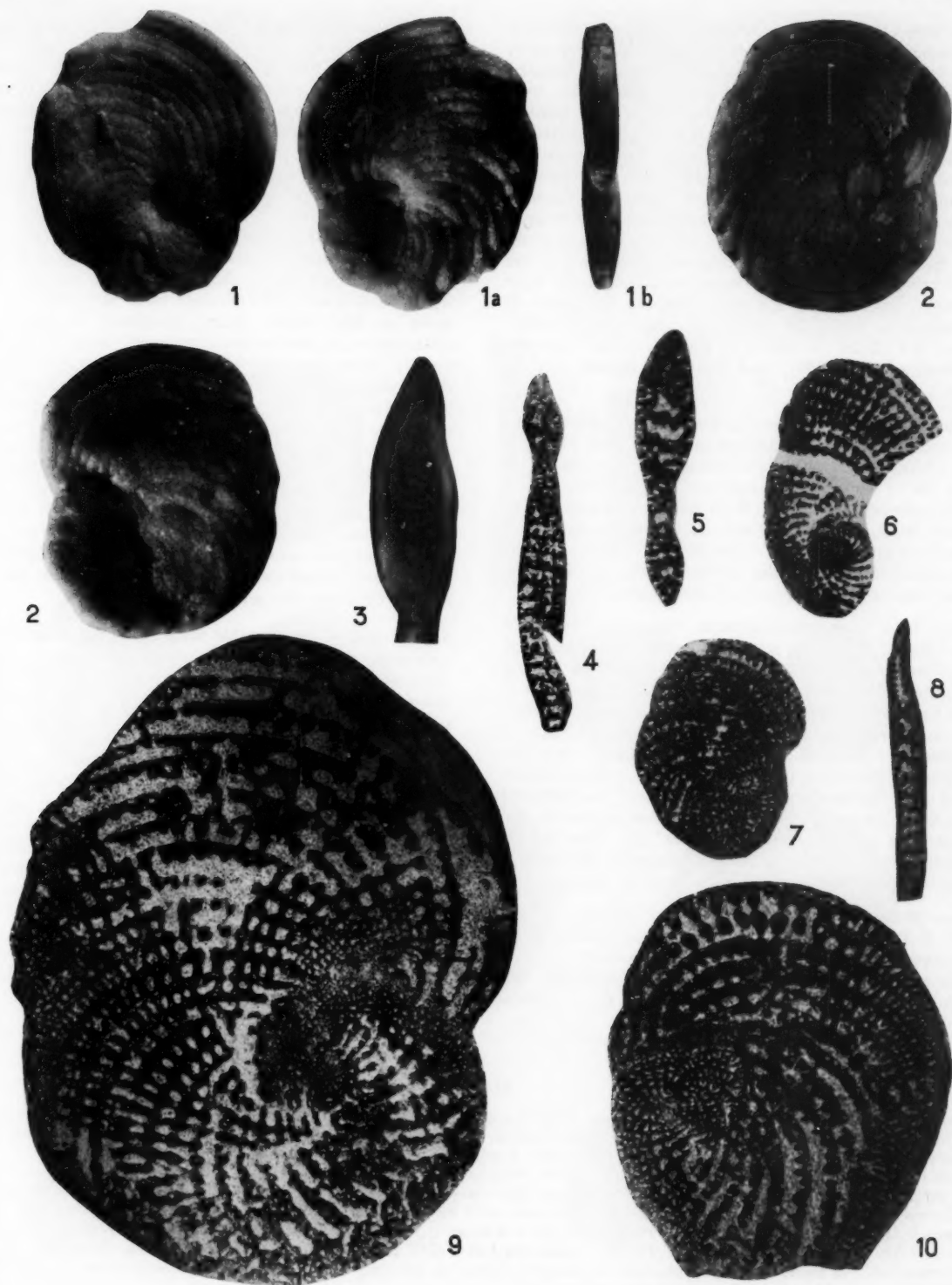
specimens from the type locality and type level (Cape Espichel in Portugal, Upper Jurassic). Unfortunately, the collection of Munier-Chalmas contains no isolated specimens of *Iberina lusitanica*, nor could the well preserved tests figured by Schlumberger and Choffat (1904, pl. 9, figs. 1–4) be located in the Schlumberger collections (Faculté des Sciences, Laboratoire de Géologie, Sorbonne; École des Mines, Paris). However, thanks to the generosity of Messrs. Antonio de Castello Branco, Director of the Geological Service of Portugal, and J. M. Pires Soares of Lisbon, it was possible to study at first hand some of the original specimens in the collection of Choffat. A neotype and hypotypoids were selected from among the well preserved specimens of "*Spirocyclina choffati*, M. Chalm. var. *lusitanica*, Choffat" from the Malm (Freixial) of Cape Espichel (Choffat collection, no. 3536), and are here figured (pl. 2, figs. 1–17).

Some additional specimens in the Choffat collection are derived from the Portlandian of Gradil (no. 3536–2), 12–13 km. south of Torres Vedras. The tests in group no. 3541 ("*Orbiculina infravalanginiensis* Choffat, 1885") were collected by Choffat from the Infravalanginian of Forte do Guincho, on the Atlantic Coast between Cabo da Roca and Cabo Razo (the most westerly points in Portugal) and from the Infravalanginian of Pisão, northeast of Murches, in the Sintra region.

Note: Some rock fragments with "*Spirocyclina*" collected by Choffat in 1883 at a locality between São Braz and Abilheira, southern Algarve, and deposited in the "Institute Supérieur Technique" at Lisbon, were sent to me by Pires Soares. These well preserved tests, however, do not belong to "*Spirocyclina*" (= *Iberina*), but to *Orbitolina (Orbitolina concava)*, and the beds in question represent, therefore, uppermost Albian or Cenomanian and not "Portlandien (Infravalanginien?)" as indicated on the accompanying label. The same applies to the numerous specimens of "*Spirocyclina*" that Pires Soares kindly collected for me at Forte do Guincho, all of which are to be referred to *Orbitolina concava* (Lamarck).

Description: 1) *External features* (see text-fig. 1 and pls. 2–3). – Test free, of variable shape (choffatelloid, peneroplid, reniform-cyclical, or discoid), usually bilaterally symmetrical; in general planispiral, but adult convolutions occasionally coiled in a slightly different plane (oligoplectoid type); walls microgranular to finely arenaceous, occasionally with coarse agglutinated material and inclusions of smaller foraminifera, about as thick as or slightly thicker than the width of the lumina; surface smooth, with pronounced, strongly arcuate sutures which are sometimes distinctly reflected on the surface (in weathered megalospheric tests) as raised costa-like ridges, in which case the periphery is not evenly rounded but jagged; the large discoid tests (generation B) usually with reniform-cyclical striae; smaller, often irregularly shaped tests (megalospheric generation) formed by a rapidly opening *Choffatella*-like spire, sometimes with a slight thickening toward the septal face, and then delimited from the latter by a more or less distinct edge; periphery rounded to subacute; in the adult microspheric test, which is a large, usually uneven or undulating disc with a somewhat thickened periphery, the closely spiral phase is succeeded by a flaring peneropline stage, which is followed sometimes by a reniform and rarely by an annular final stage (see text-fig. 1); there are fifteen to twenty-four strongly recurved chambers in the small megalospheric form, and more than twenty-four in the large form B. In a single specimen (Choffat collection, no. 3536, specimen no. 12; see pl. 2, fig. 1), the discoid microspheric test with numerous cyclical chambers exhibits a considerably raised central part, so that the test has a conical *Orbitolina*-like aspect.

Size: Owing to the variable shape, it is not possible to give any standard values of the dimensions of the test. The neotype (pl. 2, figs. 3–5), selected from the Choffat collection of the Geological Service of Portugal, Lisbon, no. 3536, no. 8, is an oval test in which the cyclical stage is reached. Its maximum diameter measures 11.40 mm., the minimum diameter 9.55 mm., and the thickness varies between 0.57 and 0.68 mm. (distal thickening). Among the hypotypoids there are tests that agree closely with the neotype, although others of the same size reveal a considerable number of cyclical chambers (pl. 2, figs. 10–13). The largest specimens observed in this microspheric series attain a maximum diameter of 15.1 mm. and 15.2 mm., respectively (pl. 2, figs. 13, 12). Small specimens ("*Spirocyclina infravalanginiensis*" of authors) showing a diameter of 1.0–1.85 mm. are attached on some of the large-sized discoid tests (pl. 2, figs. 11a, 12, 14).

PLATE 2

Iberina lusitanica (Egger), emend. Maync, external views of specimens in the Choffat collection (Lisbon): 1, original specimens of "*Orbiculina/Dicyclina lusitanica*," × 1, from the Upper Jurassic Freixial beds of Cape Espichel, Portugal, from among which the neotype was selected (no. 8; see figures 3–5 of this plate); 2, original specimens of "*Orbiculina/Spirocyclina infravalanginiensis*," × 1, from the Infravalanginian of Forte do Guincho and Pisão, Portugal; 3–5, neotype (specimen no. 8 of figure 1): 3–4, side views, × 3; 5, peripheral view, × 3; 5a, same view, × 15, showing apertural pores; 5b same view, × 30; 6–17, hypotypoids, all × 3 unless otherwise noted: 6, specimen no. 2 of figure 1; 7, specimen no. 4 of figure 1; 8, specimen no. 6 of figure 1; 9, specimen no. 7 of figure 1; 10, specimen no. 11 of figure 1; 11, specimen no. 9 of figure 1; 11a, megalospheric test attached to the specimen shown in figure 11, × 13.5; 12, specimen no. 13 of figure 1, with attached tests of the generation A-1; 13, specimen no. 15 of figure 1; 14, specimen no. 3 of figure 2, showing attached megalospheric tests; 15, specimen no. 5 of figure 2; 16, specimen no. 6 of figure 2; 17, specimen no. 11 of figure 2, a megalospheric form, × 6.
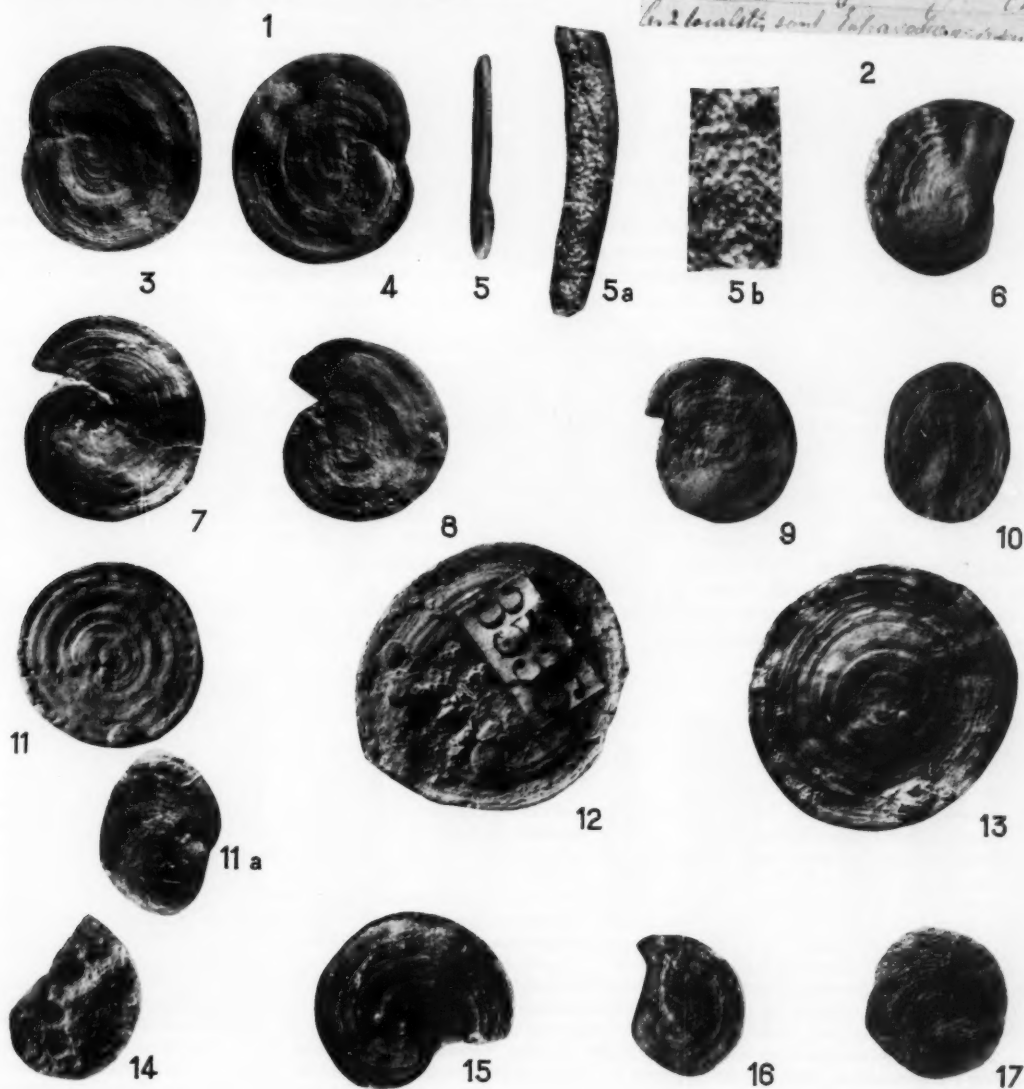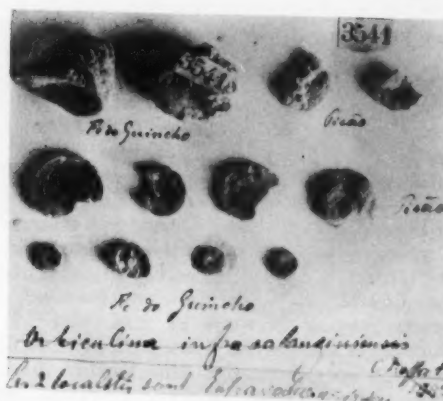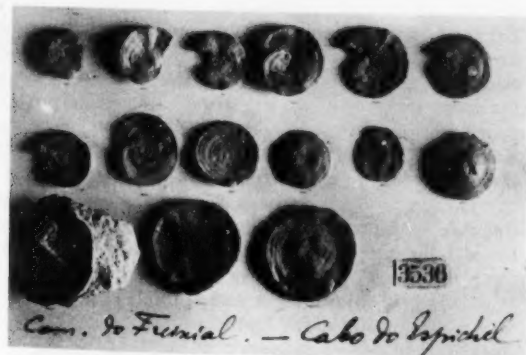
It was pointed out by Schlumberger and Choffat (1904, p. 367) that the large discoid specimens (previously denominated as *Dicyclina lusitanica*) show an average diameter of 15 mm., whereas the smaller, entirely coiled, non-discoid tests *("Spirocyclina infravalanginiensis")* rarely attain a diameter of more than 5 mm. The specimen of *Iberina* figured by Egger (1902a, pl. 6, figs. 4–5) as *Dicyclina lusitanica* represents a disc of about 12 mm. in diameter, and forms with diameters up to 20 mm. are mentioned from the Crimean Peninsula (Egger, loc. cit., p. 586). The microspheric tests from the Upper Jurassic of Cape Espichel, Portugal, show diameters ranging between 11 mm. and 15 mm. (Schlumberger and Choffat, 1904, pl. 9, figs. 1–4, 8), and another specimen from the same locality displays a diameter of 15 mm. The thin-sectioned discoid-cyclical specimen (P.2387–1) in the Schlumberger collection, reproduced in the present paper (pl. 4, fig. 1), shows a diameter of more than 18 mm. A segment of this thin section was figured in the publication of Schlumberger and Choffat (1904, pl. 9, fig. 9), but its provenience is not "Sabugo, Portugal – Infravalanginien," as erroneously indicated (Schlumberger and Choffat, loc. cit., p. 368), but Portlandian of Cape Espichel. Other microspheric tests represented in the Schlumberger collection in Paris, derived from the Infravalanginian west of Luz, Algarve, show diameters of 6–10 mm. The axial diameters of these large microspheric tests vary between 0.3 mm. and 0.9 mm. (different thickness of central and peripheral portion). The microspheric specimens from Zonguldak, northern Turkey, some of which were figured by Charles (1933, pl. 27), vary from about 5 mm. to 11 mm. in diameter.

The megalospheric tests (form A), differentiated by their much smaller size and distinct proloculus, show an average diameter of 1.4 mm. (observed minimum 0.37 mm.; maximum 2.74 mm.). All of the completely coiled tests examined which exceed 3 mm. in diameter reveal no visible proloculus, and hence represent immature individuals of the microspheric generation.

Except for the persistence of the spiral stage, that is, the absence of a reniform or even an annular phase in the adult, the megalospheric forms of *Iberina lusitanica* show the same organization as the large ones representing the generation B. As shown by the figured forms, the succession of the structural zones (1) to (3) (see below, in the discussion of internal structure) is identical, and a comparison of the specimens reproduced indicates that there is rarely an empirically perceptible difference beyond the scope of individual variability concerning the number and curvature of the central chambers, as indicated by Schlumberger and Choffat (1904, p. 361). One of the most striking features of the genus *Iberina* in the rich populations examined is the great variability of the test with regard to the external shape (see text-figure 1). As a rule, spiral tests of average size prevail, whereas large discoid forms in which the final annular stage is attained are very rarely found. In addition to small-sized, externally often *Choffatella*-like specimens (which are spirally coiled throughout), there occur even smaller semiglobular forms and others displaying a fan-shaped or flaring, typically peneropline test. Although the external shape of *Iberina* is thus highly variable, the internal structure as revealed by thin sections is absolutely identical in all the variform tests, and differentiation into a number of subspecies or species or even into different genera seems, therefore, not justified.

The test of *Iberina* initially consists of a close-coiled spire with strongly recurved septa. A reniform-cyclical phase, if developed at all, may be present only in the large microspheric generation (Cape Espichel), which proves that it is not a generic or specific criterion but an inconstant growth stage. The same fact, that is, that tests showing an embracing peneropline spire with strongly arcuate chambers often develop annular growth in maturity, has also been noted, for example, in the Meandropsinidae.

As already recognized by Schlumberger and Choffat (1904, p. 360), the different forms of *Iberina* are due to

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PLATE 3

1–8, *Iberina lusitanica* (Egger), emend. Maync, external views of the megalospheric form A-1, all × 27 unless otherwise indicated: 1, from the Upper Jurassic (lower Kimmeridgian) of Cape Espichel, Portugal; 2–3, 6, from the Infravalanginian of Djebel Zireg, Algeria; 4–5, from the Upper Jurassic (basal middle Kimmeridgian) of Djebel Zireg (Meharga), Algeria; 7, from the Infravalanginian of Djebel Zireg, Algeria (= "*Choffatella zireggensis* Sigal"), × 13.5; 8, from the Upper Jurassic (Kimmeridgian) of Repište, near Belgrade, Yugoslavia: 8, 8b, side views; 8a, peripheral view; 9–10, *Iberina lusitanica* (Egger), emend. Maync, external views of the megalospheric form A-2, × 27: 9, from the Upper Jurassic (Kimmeridgian) of Repište, near Belgrade, Yugoslavia, in association with the specimens shown in figure 8: 9, 9b, side views; 9a, peripheral view; 10, from the Infravalanginian of Djebel Zireg, Algeria, in association with the tests shown in figures 2–3 and 6–7; 11–12, *Iberina lusitanica* (Egger), emend. Maync, form A-1, showing cribrate aperture, × 27: 11, from the Upper Jurassic (lower Kimmeridgian) of Cape Espichel, Portugal; 12, from the Upper Jurassic of Djebel Zireg (Meharga), Algeria; 13–14, *Pseudocyclammina jaccardi* (Schrodt), showing the cribrate aperture, × 27: 13, from the lower Kimmeridgian (-Sequanian), in core no. 6 from Vernon well no. 1 in the Paris Basin; 14, from the middle Sequanian (Neo-Oxfordian), in an outcrop sample from southwest of Buttes, Canton Neuchâtel, Switzerland; 15–17, *Choffatella decipiens* Schlumberger, showing the aperture, a vertical series of pores: 15, holotype (Schlumberger collection, Paris), × 13.5, from the Albian of Porto do Cavalinho, Portugal; 16, another specimen, × 13.5, from the same locality (Schlumberger collection, Paris); 17, specimen from the Aptian San Juan Raya formation in the State of Puebla, Mexico, × 27.
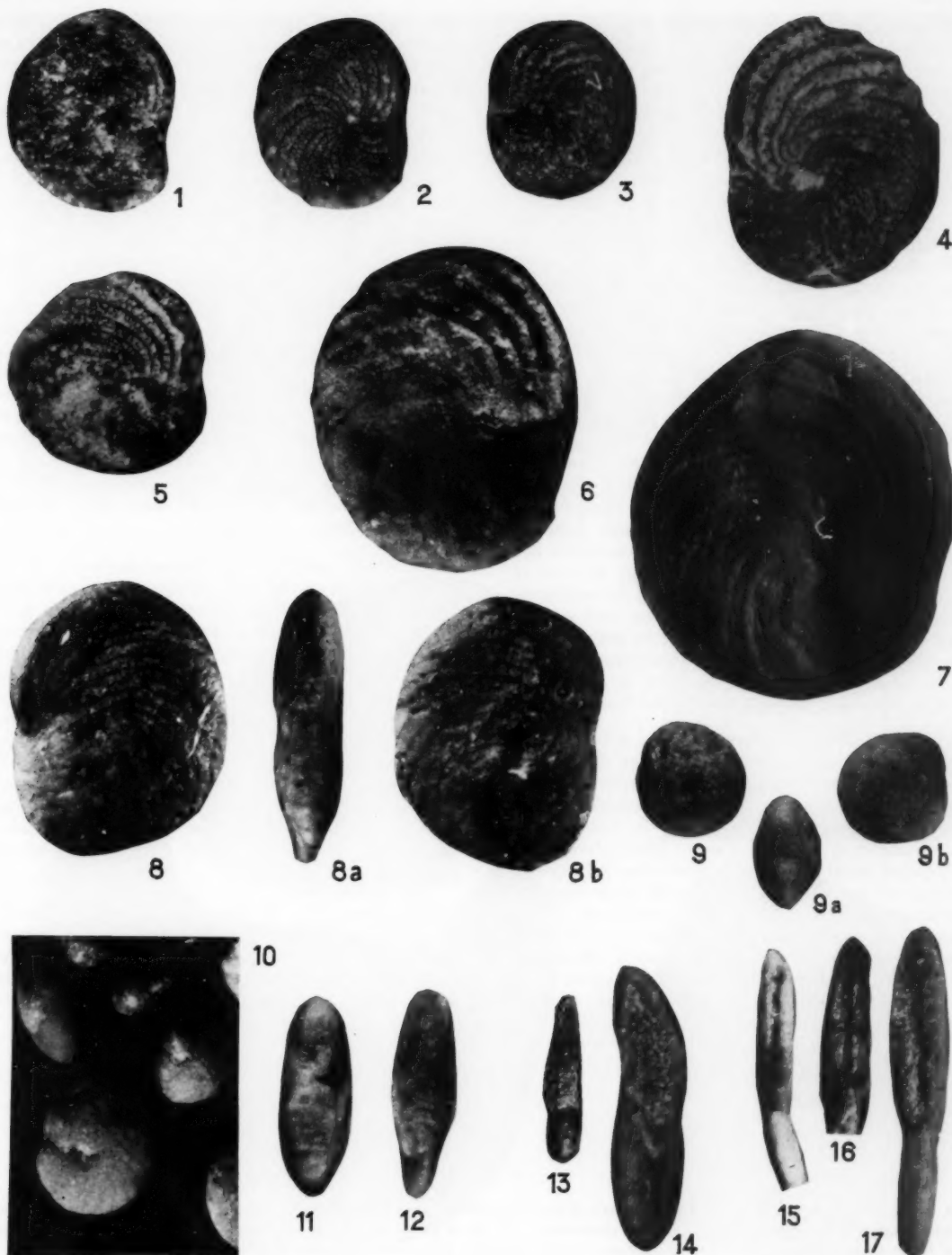
dimorphism. The two types, the smaller close-coiled tests *("Spirocyclina infravalanginiensis")* and the larger peneropline to discoid tests *("Dicyclina lusitanica")*, generally occur together (Portugal, Turkey, France, Algeria, etc.), in both Upper Jurassic and basal Cretaceous formations, and no structural differences whatsoever make distinction possible. As pointed out above, the large-sized specimens which may occasionally attain an adult cyclical stage of growth exclusively represent the microspheric form B, in which a proloculus is only very rarely discernible. Among the large number of thin sections prepared for the present study, there is only one in which the proloculus of a microspheric specimen is visible: A test from the Upper Jurassic of Cape Espichel, Portugal, is preserved in a fragment showing a radius of 4.85 mm. (the diameter of the entire specimen thus attained at least 9–10 mm.), and the visible proloculus measures 140 microns. The small tests which, because of their minute proloculi, are referable to the form B represent merely juvenile forms or the early coils of large specimens. In the prolific assemblages at hand we have never observed a large test, with a diameter greater than 3 mm., which discloses a recognizable proloculus, except for the test from Cape Espichel mentioned above; all of them are B forms, which are always accompanied by a greater or lesser number of typical megalospheric tests *("Spirocyclina infravalanginiensis")*, differentiated from the B form by their smaller dimensions and by their easily discernible proloculi. No megalospheric form in which a reniform or cyclical final stage was developed was ever observed in any of the populations studied from all parts of the world.

The mode of coiling in the microspheric generation of *Iberina lusitanica* is subject to great variation and cannot serve as a basis for taxonomic differentiation. In the material examined from the Choffat collection in Lisbon, well preserved discoid tests (pl. 2, figs. 6–9, 15–16) occur, with a diameter of 8.1 to 11.2 mm., which show completely coiled spiral growth with thirty-four to forty-five chambers (no reniform or annular stage is developed). Other large specimens of the same community at the same stage of growth, however, disclose only an insignificant early spire, and the larger portion (60–96 per cent) of the total diameter of these tests is made up of truly cyclical chambers. In the selected neotype

specimen (pl. 2, figs. 3–5), the minute initial spiral stage occupies a radius of less than 1 mm.; the greater part of the test, that is, nearly 7 mm. of the smallest diameter, is composed of about twenty-five reniform chambers, and only the latest eight to ten chambers along a radius of about 2 mm. are truly cyclical. In the largest available specimen of *Iberina lusitanica*, form B, derived from the Upper Jurassic of Cape Espichel (in the Schlumberger collection), the initial spiral arrangement is followed by closely embracing fan-shaped chambers (pl. 4, fig. 1). The early spiral stage and the succeeding flaring stage are insignificant compared with the exceedingly well developed annular stage, as they cover a diametric interval of only about 2 mm. A large number of cyclical (at first reniform) chambers then encircle the previous stages, forming the final phase. There are about seventy annular chambers in a radius of 7.5 mm. In the central portion of the test, these annuli are extremely numerous: Twenty to twenty-five annuli per millimeter of radius (the megalospheric form presents eighteen to twenty-two chambers per millimeter of radius). At the periphery, on the other hand, the chambers are broader (four to five per millimeter of radius).

Three other specimens of *Iberina lusitanica*, form B *("Spirocyclina choffati* M.-Ch."), from the Infravalanginian west of Luz in southern Portugal, are present in the Schlumberger collection in Paris. One of these tests was sectioned by the writer in order to obtain some additional information with regard to the internal organization (pl. 4, fig. 2). In two tests the final annular stage had not yet been reached; the diameters as preserved amount to 6.5 mm. and 6.1 mm., and the maximum breadth of the flaring spiral is 7 mm. and 5.7 mm., respectively. The thin section of the third fragmentary specimen shows a well developed spiral stage occupying about 3.60 mm. of the radius, and only the last eleven or twelve annuli (occupying 1.4 mm. of radius) may possibly be truly concentric.

The original of the fragmentary specimen figured by Charles from Zonguldak (1933, pl. 27, fig. 7) measures about 3.45 mm. from the center to the periphery (measurements of the original thin section, which is reproduced in pl. 5, fig. 6, of the present paper, show

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PLATE 4

Iberina lusitanica (Egger), emend. Maync, internal structure of the microspheric form: 1, median section through a very large specimen displaying a large number of circular chambers, × 5; 1a, a portion of the same section, × 27; from the Upper Jurassic (lower Kimmeridgian) of Cape Espichel, Portugal (Schlumberger collection, Paris no. P.2387-1); 2, median section of a test showing a well developed spiral stage, × 8, from the Infravalanginian west of Luz, Portugal (Schlumberger collection, Paris); 3, median section of a spirally coiled specimen, × 27, from the Infravalanginian of Charneca, Portugal (Schlumberger collection, Paris; see Schlumberger and Choffat, 1904, pl. 9, fig. 7); 4, median section of a large, completely coiled test, × 13.5, from the Infravalanginian of Charneca, Portugal (Schlumberger collection, Paris, no. P.551).
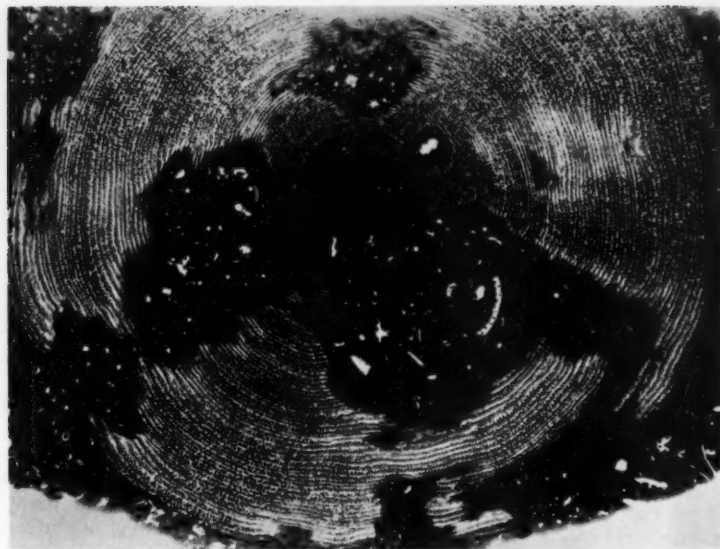
1

1a
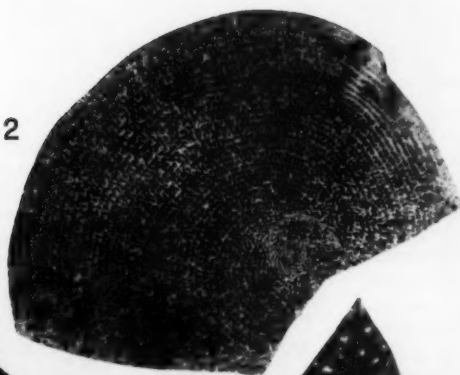
2
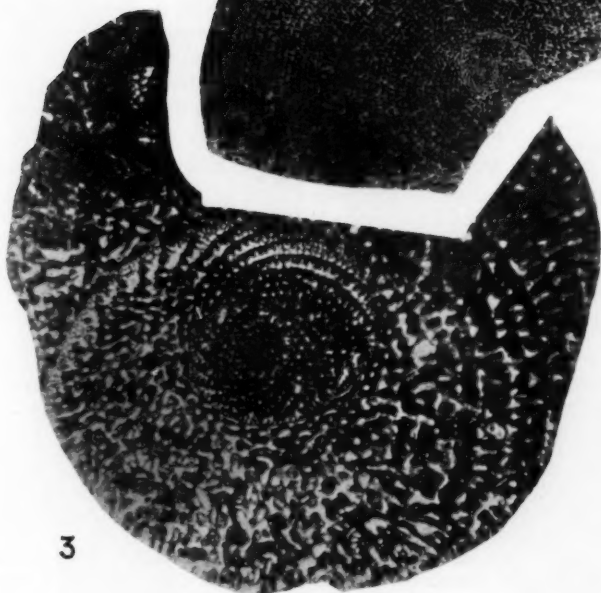
3
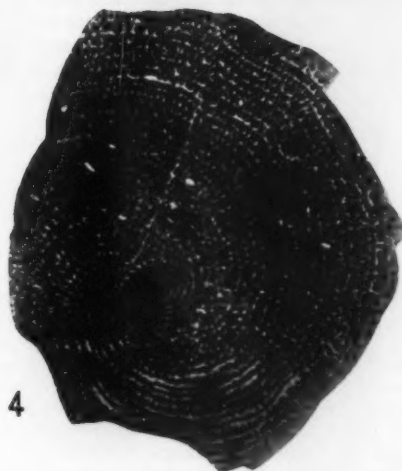
4

that the magnification is actually 26×, not approximately 16×, as stated by Charles). There are about twenty chambers recognizable along a radius of 1.7 mm. from the periphery inward, whereas near the center the same number of chambers are found to occupy only 1 mm. of radius. The central spire is obscure, and apparently only the latest few chambers, if any, are arranged in truly cyclic order.

Thus, although a given microspheric discoid test about 9 mm. in diameter shows no cyclic stage whatsoever, 80 per cent of the total diameter in other specimens of the same size may consist of annular chambers. Other specimens attaining a diameter of 10–11 mm. may show spiral growth throughout, whereas in other tests of the same dimensions the spirally coiled portion may represent only 20–35 per cent of the total diameter. It is therefore evident that the duration of the individual growth stages is not a constant morphological character upon which a system of classification might be based.

Among the available *Iberina* populations from Portugal, France, Yugoslavia, Algeria, North Carolina (U.S.A.), and elsewhere, a limited number of specimens are present which are easily distinguished from the common megalospheric tests by their usually smaller size and greater axial diameter. In thin sections, these forms show absolutely the same internal structure as the more compressed megalospheric tests of *Iberina lusitanica* (*"Spirocyclina infravalanginiensis"*), but they differ from the latter in their extremely large proloculi, which measure more than twice, and in extreme cases four or five times, the average diameter of the embryo of the common megalospheric specimens of the species (see text-figures 1–2 and pl. 8, figs. 4–15). These considerable differences obviously exceed the normal range of individual variability. Since the semiglobular specimens with a larger proloculus occur together with the larger megalospheric ones, not only in the same stratum but even in the very same samples, the more inflated form with the enormous proloculus cannot represent a race or subspecies but is actually a morphotype and thus part of the species *lusitanica*. In other words, its different morphological characters are not due to allopatric

factors (restriction to a certain area because of geographic or ecological isolation, for example), nor can this form be taken as a morphologically distinct variant within the hypodigm of *Iberina lusitanica*, as it is not linked by intermediate forms with the megalospheric specimens normally found (see text-figure 2). From the presence of tests of this peculiar form with an extremely voluminous proloculus in the same samples which contain megalospheric specimens with a considerably smaller nucleus, as well as microspheric tests, the conclusion is drawn that *Iberina lusitanica* develops three different types of test, viz., an A–1, an A–2, and a B form (trimorphism).

Specimens of "*Spirocyclina infravalanginiensis*" showing a large proloculus were figured previously by Egger in his memoir on the orbitolinids (1902a, pl. 5). According to that author, the diameters of the tests reproduced in figures 3 and 8 amount to 0.8 mm., and those of the specimens depicted in figures 4 and 11 are 0.9 mm. Based on the given size of these tests, the proloculi attain the following diameters: 200 microns (fig. 3); 250 microns (fig. 4); 180 microns (fig. 8); and 360 microns (fig. 11). If these values are plotted in our diagram (text-figure 2), the four tests obviously fall into the area of the A–2 generation of *Iberina lusitanica*. A specimen showing a large proloculus (390 microns) has also been figured from the Swiss Alps (Maync, 1938, pl. 4, fig. 11; see also pl. 8, fig. 14).

Supposedly, this test trimorphism is not only morphological but also biological in nature: The microspheric form B (schizont) is the result of sexual copulation (amphimixis) by gametes, which are produced by the gamont generation A (gametogony). The latter agametic generation, formed by asexual reproduction of the zygote B, obviously shows morphological and physiological differentiation into the two different forms A–1 and A–2.

To sum up, our detailed investigation based on prolific material from many parts of the Tethys province has revealed that the large, occasionally discoid tests which are characterized by a very tiny proloculus and a reni-

PLATE 5

Iberina lusitanica (Egger), emend. Maync, internal structure of the microspheric form: 1, specimens from the Infravalanginian of Forte do Guincho, Portugal, × 13.5 (Schlumberger collection, Paris, Douvillé no. 613), associated with megalospheric tests; 2–5, 7–11, transverse sections: 2, from the Upper Jurassic (lower Kimmeridgian) of Cape Espichel, Portugal, × 13.5 (Schlumberger collection, Paris, no. P.2387-2); 3, from the Upper Jurassic(-Infravalanginian) on the road between Gradil and Vila Franca do Rosario, Portugal, × 13.5 (collected by Pires Soares, 1958); 4, from the Infravalanginian of Sabugo, Portugal, × 13.5 (Schlumberger collection, Paris, no. P.2390); 5, from the Upper Jurassic (or basal Cretaceous?) of Zonguldak, Turkey, × 27 (see Charles, 1933, pl. 27, fig. 4); 7–8, from the Infravalanginian of Djebel Zireg, Algeria (= "*Choffatella zireggensis* Sigal"), × 27; 9, from the Upper Jurassic of Djebel Zerga, Algeria, × 27; 10, from the Upper Jurassic Quemado limestone of Las Villas Province, Cuba, × 27; 11, from the Upper Jurassic, in core at 9115–9116 feet in Cape Hatteras Light well no. 1, North Carolina, U.S.A. (= "*Anchispirocyclina henbesti* Jordan and Applin"), × 27 (U. S. Geological Survey collection, Washington, D. C.); 6, median section, × 13.5, from the same locality as in figure 5 (see Charles, 1933, pl. 27, fig. 7).
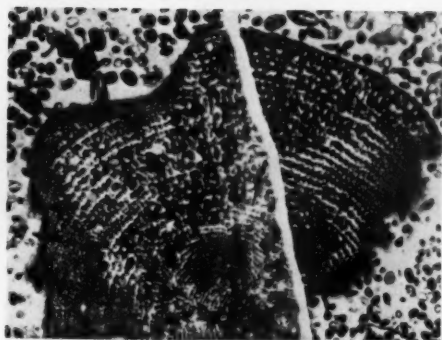
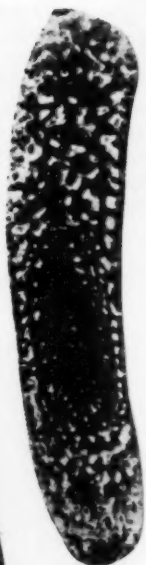form, rarely cyclical adult stage do not represent a distinct species *("Dicyclina-Spirocyclina lusitanica"* of authors), as hitherto assumed, but are the microspheric (B) form of *Iberina lusitanica.* The very common smaller, completely coiled tests with a larger embryonic chamber correspond to the megalospheric form A–1 of *Iberina lusitanica ("Spirocyclina infravalanginiensis"* of authors). The small, often inflated form with an enormous proloculus is believed to represent the megalospheric form A–2. These conclusions are supported by the fact that the complex internal organization of all of these externally different forms is identical, so that differentiation into separate species is not warranted.

Although the average size of the A–1 form of *Iberina lusitanica* is 1.4 mm. (the largest and the smallest specimens observed show diameters of 2.74 mm. and 0.62 mm., respectively), no mature microspheric specimens showing diameters of less than 2.85 mm. were encountered. The average size of the B form is 4–6 mm., and very large tests attaining 10 mm. and more (up to more than 18 mm.) in diameter are available only from Portugal and Zonguldak.

The ratio of maximum diameter to thickness is highly variable. In the A–1 generation, it ranges between 2.6:1 and 8:1, with an average of 4:1 or 5:1. In the A–2 form, it varies between 1.6:1 and 4:1 (test generally thicker than that of the A–1 generation). In the microspheric tests, this ratio is much higher and may, in the large discoid forms, attain extreme values of 30:1 or 40:1.

As is evident from the diagram given in text-figure 2, the diameter of the proloculus in the megalospheric generation becomes progressively slightly larger with increase in the size of the tests. In the form A–1, the proloculi range from 60 microns (specimen 0.77 mm. in diameter) to a maximum of 260 microns (large test with a diameter of 2.20 mm.). For the common tests up to 2 mm. in diameter, the proloculi average 140 microns, and for those exceeding 2 mm. in size, the proloculi average 190 microns. In the A–2 generation, the proloc-

uli range in diameter from 140 microns (smallest test, showing a diameter of 0.37 mm.) to 450 microns (test 2 mm. in diameter), with an average proloculus size of 260 microns.

Biometric studies of the megalospheric generations of *Iberina lusitanica* result in the following general rule:

Size of proloculus	Diameter of test			
	up to 0.6 mm.	0.6–1.1 mm.	1.1–2 mm.	larger than 2 mm.
>130 microns	A–2			
<130 microns		A–1		
>180 microns		A–2		
<250 microns			A–1	
>250 microns			A–2	
<300 microns				A–1
>300 microns				A–2

The crucial fact that the two sharply delimited empirical areas discernible in the diagram (text-fig. 2) are non-transitional and do not overlap suggests that multiple intermediate forms do not exist within the A generation. Hence there seems to exist, at least in *Iberina lusitanica,* not polymorphism but clear-cut trimorphism in the sense of Hofker.

There exist, as in other groups of foraminifera, great differences concerning the frequency of either micro- or megalospheric tests of *Iberina lusitanica* in a given stratum. In one place, tests of the B form may predominate, although the same bed at another locality may harbor megalospheric specimens almost exclusively. This inconstancy is apparently due to unfavorable living conditions which may lead to modifications in the reproductive processes of the species. When the ability to produce new gamonts is unfavorably affected, sexual biogenesis will naturally prevail (predominance of B forms). If, on the other hand, sexual activity decreases for one reason or another, schizogenesis (asexual fission) and thus a preponderance of megalospheric tests will obviously result.

PLATE 6

Iberina lusitanica (Egger), emend. Maync, internal structure of form B: 1, median section, × 18, from the Upper Jurassic (Kimmeridgian) of Repiste, near Belgrade, Yugoslavia; 2, median section, × 13.5, showing incorporated nodules, from the middle Kimmeridgian ("Portlandian") in core 26 (2576.05 meters) from Esso R.E.P. Parentis well no. 19, Aquitaine, France; 3, median section, × 27, from the Infravalanginian (-Valanginian) of Djebel Zireg (Meharga), Algeria; 4–5, median sections, × 27, showing the labyrinthic structure of the innermost zone, from the Upper Jurassic (basal middle Kimmeridgian) of Djebel Zireg (Meharga), Algeria; 6, median section, × 13.5, from the Infravalanginian of Djebel Zireg, Algeria ("*Choffatella zireggensis* Sigal"); 7, median section, × 13.5, from the Upper Jurassic (?lower Kimmeridgian) of Tiaret, Algeria (Schlumberger collection, Paris, no. P.205); 8–10, topotypes of "*Anchispirocyclina henbesti* Jordan and Applin" from the Upper Jurassic, in core at 9115–9116 feet in Cape Hatteras Light well no. 1, North Carolina, U.S.A. (U. S. Geological Survey collection, Washington, D. C.): 8, part of an equatorial section, × 13.5; 9, median section, × 13.5, associated with megalospheric tests (form A-1); 10, median section, × 27, showing coarsely arenaceous texture of central zone.
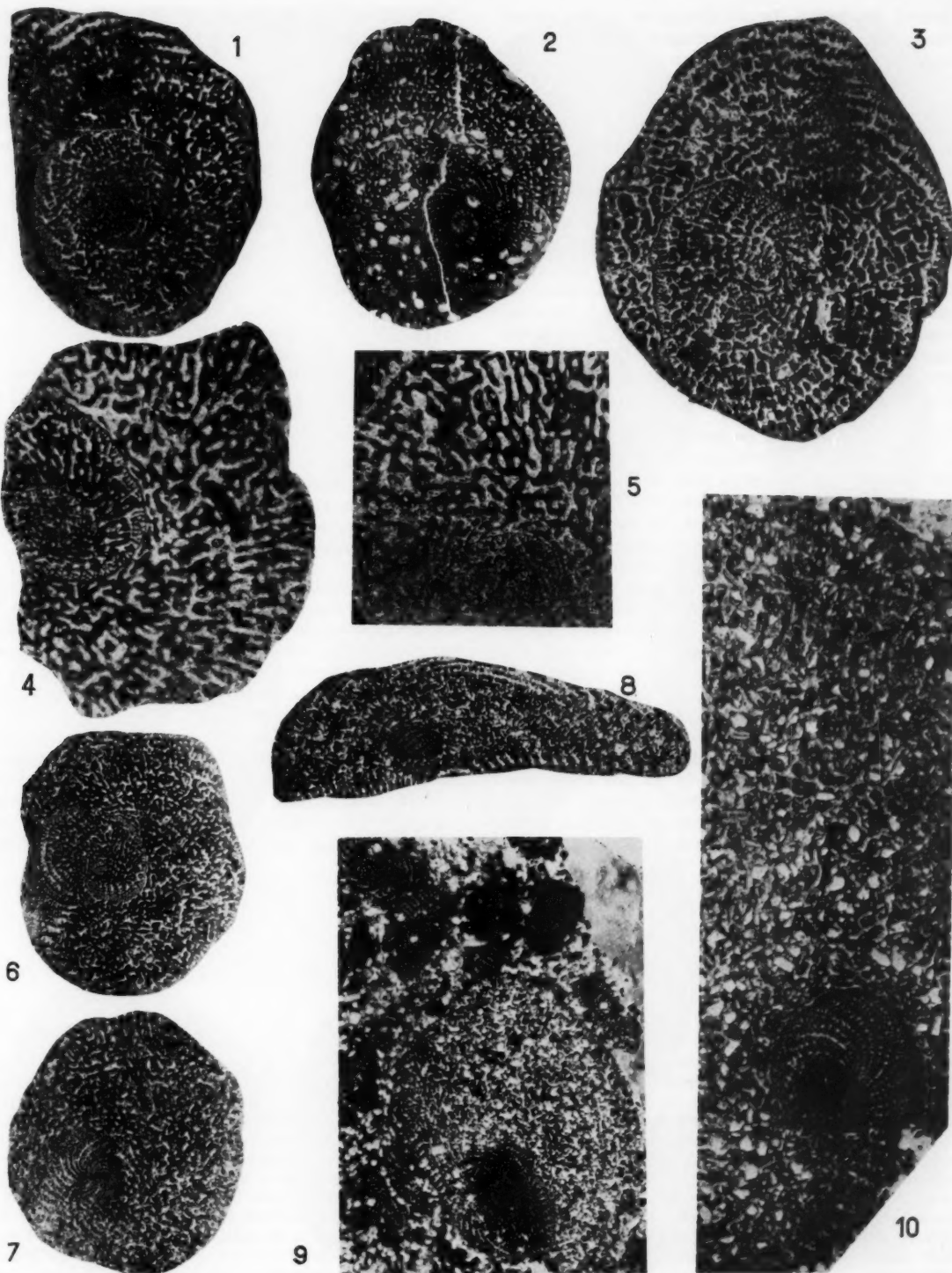
2) *Internal structure.* – In his definition of the genus *Iberina*, based on *Dicyclina lusitanica* from Portugal, Munier-Chalmas differentiated an external alveolar layer and an internal zone characterized by a coarser meshwork, which overlies the walls of the annular chambers. He furthermore stressed the fact that regular rectangular chamberlets, formed by subdividing radial septula in the primary chambers, are absent in *Iberina* but are well developed in *Cuneolina-Dicyclina* (Munier-Chalmas, 1902, pp. 350–351).

As for the conclusions reached by Egger (1902*a*), we refer to our remarks given previously in the "Historical Review." Because of the mode of presentation in Egger's treatise, no discrimination can be made between factual evidence and inference, the forms treated belonging to different genera and the greater part of the figured specimens remaining problematical with regard to their geographic and stratigraphic provenience.

In his fundamental paper on *Spirocyclina* from Portugal, that is, on the form differentiated by Munier-Chalmas (1902) as *Iberina*, Schlumberger presented further details on the structure of the genus (Schlumberger and Choffat, 1904, pp. 360–362). It was pointed out that the juvenile stage consists of a number of spirally arranged chambers which, due to their more and more embracing character, gradually become annular, so that the adult test is finally represented by a circular disc. The small tests in which the cyclic stage is not yet reached are nearly always the megalospheric generation (form A), whereas the large discoid tests, revealing a greater number of chambers in the initial spire and exhibiting more closely recurved lumina, represent the microspheric form. According to Schlumberger, the chambers throughout all stages of growth are subdivided by numerous transverse septa which do not reach the opposite (preceding) chamber wall; in this way, a circular channel is formed by means of which communication within each chamber is maintained.

Schlumberger finally concluded (loc. cit., p. 362) that the specimens from the Upper Jurassic and basal Cretaceous, respectively, of Portugal (and Algeria), and those from the Senonian of southern France, are conspecific (*Spirocyclina choffati* Munier-Chalmas, *fide* Schlumberger). The Senonian genus *Spirocyclina* was thus extended to include the Portuguese forms, which show a fundamentally different internal organization.

Since the large tests were reported as occurring mainly in the Portlandian, and the small ones chiefly in the basal Cretaceous of Portugal, Schlumberger and Choffat suggested that these forms should be differentiated as varieties, to be called *Spirocyclina choffati* var. *lusitanica* and *Spirocyclina choffati* var. *infravalanginiensis* (loc. cit., p. 367). This conclusion is in disagreement with the idea expressed in the same publication (loc. cit., p. 359) that "*Dicyclina*" *lusitanica* and "*Spirocyclina*" *infravalanginiensis* merely represent ontogenetic stages of a single form. As for the internal structure of "*Spirocyclina*" from the Upper Jurassic and Lower Cretaceous of Portugal, Douvillé (1906, pp. 594–595) stated that the arenaceous alveolar test rapidly becomes cyclical, that the septa are pierced by apertures, and that more or less lamelliform pillars, irregularly intercalated between the apertural passages, develop in the interior.
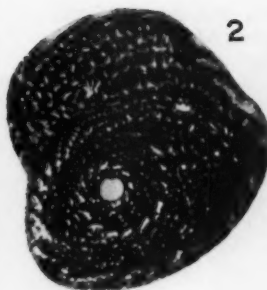
In his publication on "*Spirocyclina*" from northern Turkey, Charles (1933, p. 467, etc.) discriminated an imperforate cuticle underlain by an alveolar sub-epidermal layer formed by a polygonal meshwork, which leads inward to a series of subcortical pillars (extending at right angles into the interior), some of which form radial, irregular, not strictly continuous partitions of the primary chambers. The subcentral and central portions of the test are occupied by a coarsely labyrinthic zone with incorporated foreign particles. Owing to the fact that the thin sections of "*Spirocyclina*" from Zonguldak were believed to differ in some minor points from the species described and figured from Portugal, Charles

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PLATE 7

Iberina lusitanica (Egger), emend. Maync, internal structure of the megalospheric form A-1: 1, from the Infravalanginian of Forte do Guincho, Portugal, × 27 (Schlumberger collection, Paris, Douvillé no. 612); 2, from the Infravalanginian of Charneca, Portugal, × 27 (Schlumberger collection, Paris, no. P.546; see Schlumberger and Choffat, 1904, pl. 9, fig. 6); 3–4, from the Upper Jurassic (lower Kimmeridgian) of Cape Espichel, Portugal, × 27; 5, from the Purbeckian of Étournelles, Mt. Salève, Haute-Savoie, France, × 27; 6–7, from the Upper Jurassic (Kimmeridgian) of Repište, near Belgrade, Yugoslavia, × 27; 8, from the Upper Jurassic-Infravalanginian of Ramales, Spain, × 27; 9, from the Upper Jurassic (middle Kimmeridgian), in core no. 6 (486 meters) from Beynes well no. 6, west of Paris, × 13.5; 10, from the Upper Jurassic (lower Kimmeridgian) of Tagdempt (Tiaret), Algeria, × 27, the regular internal structure largely obliterated by excessive agglutination of foreign material (Le Mesle collection, Museum of Natural History, Paris); 11, 14, from the Upper Jurassic (basal middle Kimmeridgian) of Djebel Zireg (Meharga), Algeria, × 27; 12, axial section, × 27, from the Infravalanginian (-Valanginian) of Djebel Zireg, Algeria; 13, axial section, × 27, from the Upper Jurassic (lower Kimmeridgian) of Tiaret, Algeria (Schlumberger collection, Paris, no. P.849, leg. Welsch); 15, oblique section through center, × ca. 50, from the Upper Jurassic-Lower Cretaceous of Ponta do Escorregadeiro, São Nicolau Island, Cape Verde Archipelago (after Sousa Torres and Pires Soares, 1946, pl. 18, fig. 5).
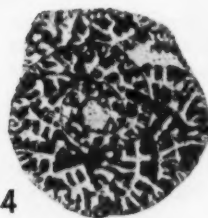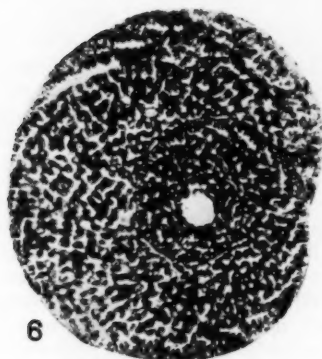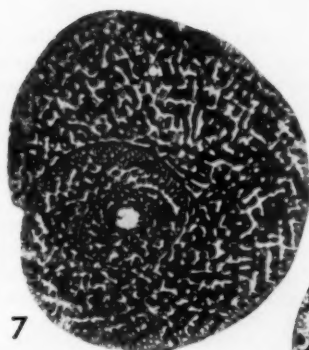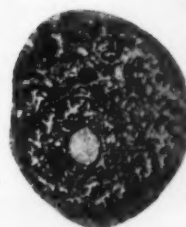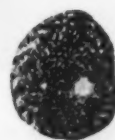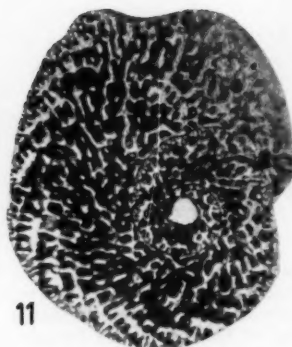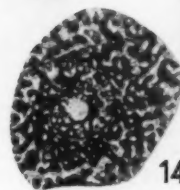
established the new variety *euxina*, and described the Turkish form as *Spirocyclina choffati* Munier-Chalmas var. *euxina*.

In his paper on *Orbitammina elliptica* (d'Archiac), a large foraminifer from the Bathonian of northeastern France, Bonte (1944, p. 339, etc.) also discussed the internal structure of the genus "*Spirocyclina*." According to that author, the alveolar subepidermal layer, which is present in "*Spirocyclina*" but absent in *Orbitammina*, is a purely ecological feature, which can be disregarded from a taxonomic point of view (Bonte, 1944, p. 344), a concept which is most certainly not shared by the present writer.

Bonte based his classification of "*Spirocyclina*" and some other genera on the development of the various stages of coiling, and differentiated, for example, tests showing a spiral-reniform stage throughout *(Orbitammina)* from others that become rapidly cyclical *(Orbitopsella)*, and from forms which display a long spiral phase followed by a short reniform and sometimes a final annular stage *(Spirocyclina)*. That such a classification is *per se* arbitrary and of no taxonomic value is proved, for example, by the assemblage of *Iberina lusitanica* in the original collection of Choffat, in which all of these different growth stages exist within one species (see pl. 2 and text-figure 1). Bonte drew attention to a zone of unpartitioned concentric chambers ("canaux circulaires") beneath the sub-epidermal layer in "*Spirocyclina*," a feature which had already been noted by the author of the genus *Iberina* (Munier-Chalmas, 1902, p. 350; Bonte, 1944, p. 343, etc.). Such a narrow zone of open primary chambers has also been recognized in the genera *Orbitammina, Orbitopsella, Saudia,* and others.

In his memoir on the larger forminifera of southwestern Asia, Henson (1948, pp. 19–20, pl. 10, figs. 8?, 9; pl. 13, figs. 1–2, 5–6) described "*Spirocyclina* sp." from Saudi Arabia. Reviewing the internal structure of the available specimens, Henson stated that the chambers beneath a thin sub-epidermal layer (with transverse and parallel plates) show a labyrinthic structure, which is "due to the development of lamelliform buttresses coalescing to form reticulate partitions; these structures are independent of the sub-epidermal partitions, and communication throughout each chamber is provided by continuous passages lying between the sub-epidermal and central zones on either side of the test" (loc. cit., p. 20). These "canaux circulaires," which occur directly beneath the sub-epidermal layer and which are clearly visible in both median and transverse sections, represent a narrow zone of open, that is, not subdivided chambers (see above). In view of the fact that "their early stages are identical" (loc. cit., p. 20), the close relationship between "*Spirocyclina*" and *Choffatella* is underlined. Only a few specimens of "*Spirocyclina* sp." have as yet been recorded from the Upper Jurassic of the Qatar Peninsula. Judging from the figures given by Henson (pl. 10, fig. 9; pl. 13, figs. 1–2), these tests show an internal structure similar to that of *Iberina*, although the central zone is less typically developed.

The genus *Anchispirocyclina*, established for North American Upper Jurassic specimens in which a reniform or annular adult stage is not developed (Jordan and Applin, 1952, p. 4), was placed in synonymy with "*Spirocyclina*" of authors (= *Iberina* Munier-Chalmas) because it agrees completely with the latter insofar as its internal structure and dimensions are concerned (Maync, 1956). True enough, the North American tests show agglutination of much arenaceous material, but such textural differences are entirely a function of the prevailing environmental conditions and are present also in other arenaceous genera, such as *Choffatella, Pseudocyclammina, Orbitolina,* etc. With regard to the non-development of truly reniform growth, it should be borne in mind that this stage is by no means attained at a certain phase of growth in *Iberina*, but may develop earlier or later and is observed only in large microspheric tests (see text-figure 1). The same applies to the cyclic mature stage, which, however, is very rarely reached.

Jordan and Applin give the following analysis of the internal structure of *Anchispirocyclina*: "(1) a thin, subepidermal cellular layer, composed of fine, intersecting partitions that form a delicate, reticulate pattern, similar to that present in the Orbitolinidae but less regular; (2) below this superficial structure, the chamber walls are composed of a linear series of lamelliform buttresses separated by narrow, intraseptal canals. The buttresses align from one septum to the next, and partly fill the chamber area, leaving a narrow, open passage that borders the preceding chamber wall; (3) central, or innermost, portion of the test occupied by a labyrinthic type of structure that probably represents the spreading and anastomosing inward projections of the buttresses

PLATE 8

Iberina lusitanica (Egger), emend. Maync, internal structure, all × 27 unless otherwise noted: 1–3, megalospheric form A-1, median sections, from the Infravalanginian of Djebel Zireg, Algeria ("*Choffatella zireggensis* Sigal"); 4–15, megalospheric form A-2: 4–11, from the Upper Jurassic (lower Kimmeridgian) of Cape Espichel, Portugal: 4–10, median sections; 11, axial section; 12, 15, from the Infravalanginian (-Valanginian) of Djebel Zireg (Meharga), Algeria: 12, oblique section through megasphere; 15, equatorial section; 13, from the Upper Jurassic of Djebel Zerga, Algeria; 14, from the Upper Jurassic-Infravalanginian of Herrenrüti (Engelberg), Switzerland, × ca. 22.5 (after Maync, 1938, pl. 4, fig. 11).
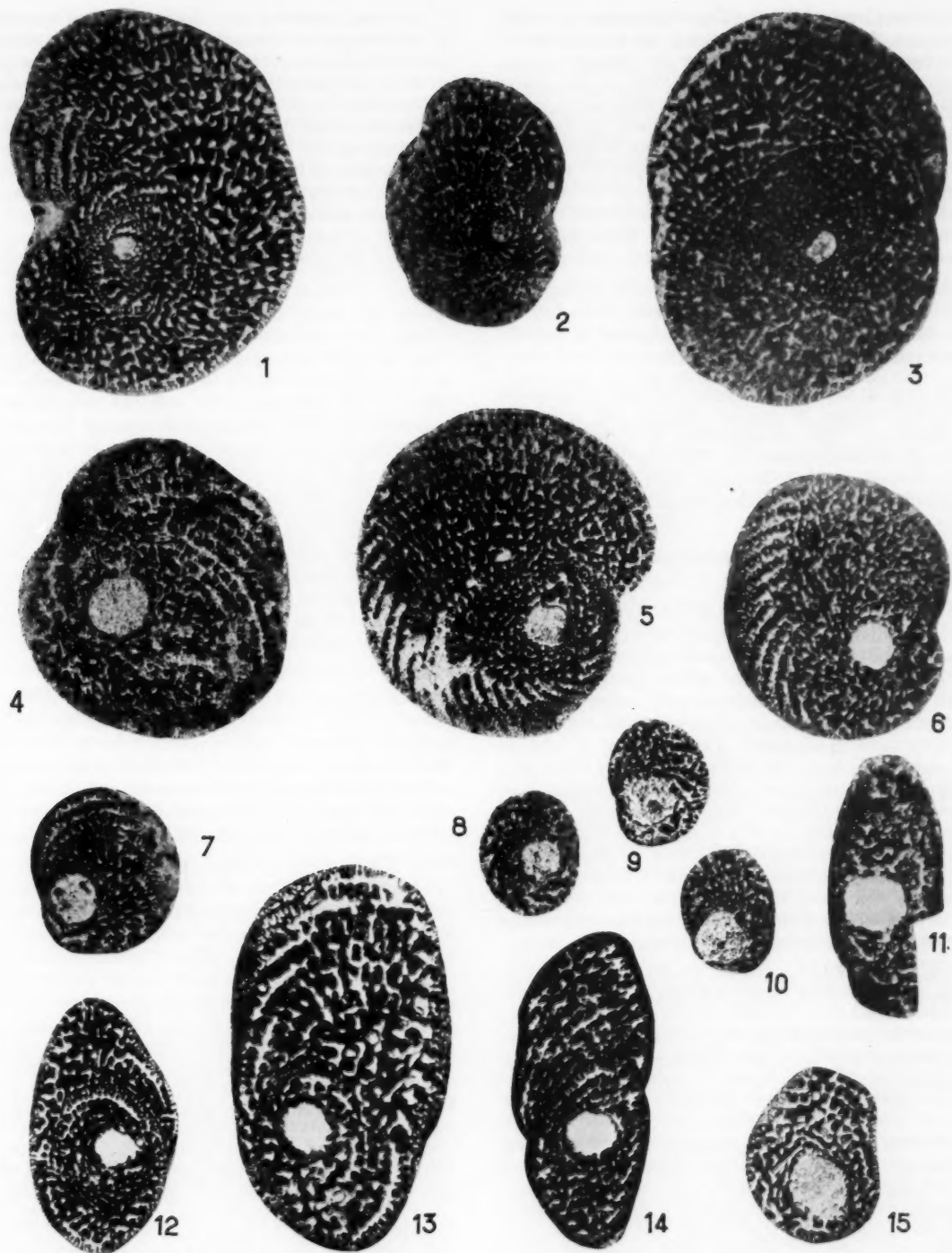
seen in the second layer. This feature retains some structural regularities, and could be more precisely described as 'semilabyrinthic' or by the term 'non-labyrinthic' as defined by Maync (1949, p. 536). Some sand grains are incorporated in this third layer, and a few are seen in other interior portions of the test" (Jordan and Applin, 1952, p. 4). As will be pointed out below, this structural interpretation must be modified with respect to the middle layer (2), in which an open zone with nonseptate chambers is developed and in which the septa are regularly pierced by the apertural passages *(Choffatella* stage).

If the pertinent observations of previous authors are combined with the results of our own research, the internal structure of *Iberina* is interpreted as follows: The imperforate epidermis is underlain by

1) an alveolar sub-cuticular layer (network of polygonal meshes formed by minute parallel and transverse partitions). This sub-epidermal zone, which shows identical development in *Choffatella* and in *Pseudocyclammina jaccardi* (formerly *sequana*) and *Pseudocyclammina jaccardi personata*, measures 40–50 microns in thickness.

Immediately beneath this reticulate sub-epidermal layer lies

2) a zone in which the narrow arcuate chambers are not subdivided by any interseptal elements, and in which the choffatelloid septa are seen to be pierced at right angles by regularly spaced apertural canals. In this open zone, the internal organization of *Iberina* is consequently identical with that found throughout in *Choffatella*. The statement of Schlumberger and others that all the lumina are subdivided throughout into more or less isolated chamberlets by secondary transverse septula extending inward without reaching the wall of the preceding chamber must thus be modified. This zone of unpartitioned chambers *(Choffatella* stage) shows a thickness in the last-formed whorl ranging from 40 to 110 microns, varying with the size of the particular test. In the early coils it is less than 20 microns.

The zone of open chambers is underlain by the subcentral and central zones, which are occupied by

3) an irregular labyrinthic structure due to the development of projections ("lamelliform buttresses"; "piliers cylindriques") which extend radially inward from one septum toward the preceding one. These elongate interseptal appendices that form intermittently between the apertural passages are partially continuous, so that each primary chamber is irregularly and incompletely subdivided into smaller compartments by the jutting buttresses, which may coalesce with the preceding septal wall. The transition from the open zone (2) into the next deeper one (3) is gradual: The individual segments between the interseptal canals of a given septum show only some insignificant inward swellings in the portion that

directly underlies the *Choffatella* stage; toward the central parts, these processes become more and more protrusive and irregular until they grow together with the preceding septum, forming in this way a complex labyrinthic structure. Since the perpendicular canals that divide each septum into numerous segments are more or less in alignment from one chamber to the next (not alternating in position), some of the lamelliform projections developed may extend radially across several cycles (pls. 4–8).

The presence of the irregular retiform pattern of the subcentral and central zones (3) is a highly diagnostic feature of *Iberina*. Because of this labyrinthic core, the genus can easily be distinguished from *Choffatella*, in which the individual septal segments (separated from each other by intraseptal canals) may occasionally show a faint bulge toward the interior of the chambers, but the lumina themselves are void of any interseptal elements. In axial sections of *Iberina*, the zone of open chambers, which is distinctly visible on both sides of the test (pl. 5, figs. 2–5, 7–11; text-fig. 3a–d), is bounded toward the interior by this labyrinthic pattern of the innermost zone; the nonseptate chambers are, in other words, not continuous across the test but are visible in two narrow parallel zones between zone (3) and the subcortical layer on either side. In *Choffatella* and *Pseudocyclammina*, on the other hand, the chamber cavities continue from one side to the other without being interrupted by a complex central zone (see text-fig. 3).

Other morphologic features which permit differentiation of the genera *Iberina* and *Choffatella* are the more strongly recurved septa in the former genus, and the different apertural character: In *Choffatella*, the openings are arranged in a vertical linear series, whereas in *Iberina* they are regularly distributed over the entire septal face, as in *Pseudocyclammina* (see pl. 3, figs. 11–17).

The succession of the structurally different zones (1) to (3) as outlined above is evident in both median and transverse sections, especially in the large microspheric forms. Because of irregular undulations, these discoid tests are usually cut at different depths and therefore show the different zones (1) to (3) and their geometric positions very clearly (pl. 4, fig. 1, 1a; pls. 5–8). The same applies to the axial sections (pl. 5, figs. 2–5, 7–11; text-fig. 3a–d), and we believe that the structural zones distinguished, their relations, and their respective succession manifest themselves distinctly also in the other photomicrographs published with the present paper.

With regard to the internal structure, *Iberina* is closely similar to *Saudia* Henson, 1948, described from the Lower Eocene and Paleocene of Saudi Arabia (Henson, 1948; Grimsdale, 1952). In that genus, which was referred by its author to the family Meandropsinidae and subsequently to the Peneroplidae, the alveolar sub-epidermal layer is also underlain by a zone of open (undivided) chambers; in the core of the test, radial interseptal

buttresses develop, which are, however (contrary to *Iberina*), regularly aligned across the annular chambers (Henson, 1948, pp. 97–98, pl. 12, figs. 1–5). Moreover, *Saudia* differs from *Iberina* in the considerable distal thickening (at the periphery the test is several times as thick as in the center). The structural similarities to *Iberina* are particularly obvious in the species *Saudia labyrinthica* Grimsdale, recorded from the Paleocene of Iraq (Grimsdale, 1952, pp. 230–231, pl. 21, figs. 1–4; pl. 22, figs. 1–2), in which the interior zone not only is especially well developed but also shows an irregular structure of pillars and buttresses (labyrinthic zone).

AGE OF THE IBERINA-BEARING BEDS

Portugal

According to Choffat, who was the first to find and record *Iberina* ("*Orbiculina*"; "*Dicyclina*"; "*Spirocyclina*") in Portugal, the large discoid form occurs chiefly in the uppermost Jurassic of Cape Espichel and Sintra, in the southern Torres Vedras area, and in southern Portugal (Algarve), whereas the small coiled test ("*Spirocyclina infravalanginiensis*") is very common at the top of the Jurassic of western Algarve and in the Infravalanginian of the region of Sintra and in eastern Algarve (Choffat, 1885, 1887, 1901, 1904). The two types of tests, that is, "*Dicyclina lusitanica*" and "*Spirocyclina infravalanginiensis*," occur together, however, in the Upper Jurassic and Infravalanginian of Algarve (Choffat, 1887, p. 273, etc.; 1901, p. 134, etc.). The same association is recorded in the region of Sintra, and is also evident in the samples examined from Cape Espichel. The statement cannot be confirmed that the large form is more common at Cape Espichel than the smaller tests (Schlumberger and Choffat, 1904, p. 366), but in a sample from Gradil, the large tests (= microspheric generation) predominate by far. In the Sintra region, on the other hand, the small forms ("*infravalanginiensis*" type) are reported to occur in greater numbers than the large tests (Choffat, 1885, p. 4), and in a section on the beach at Almadena (southern Algarve), the large "*Dicyclina lusitanica*" is recorded from a slightly higher stratigraphic level than "*Spirocyclina infravalanginiensis*" (Choffat, 1887, p. 275). It is thus clear that the idea that either type possesses any stratigraphic significance can hardly be maintained. Some of the *Iberina*-bearing samples examined from Portugal were collected at the type locality of the genus, Cape Espichel. On this promontory, a section of northwesterly-dipping sediments of Lower to Upper Jurassic age is exposed, and the cape itself is formed by "Portlandian" *Iberina*-bearing beds which in turn are overlain by Lower Cretaceous (Lagosteiros).

The stratigraphic sequence from the Liassic to the Oxfordian in the Lusitanian trough is discussed in a recent publication (Schott and Staesche, 1957), and there are also stratigraphic and paleontological papers on the upper Malm and Cretaceous sections (Zbyszewski, 1955; Zbyszewski and d'Almeida, 1955; Mempel, 1955; Oertel, 1956). The Upper Jurassic complex in the Lusitanian trough, which is characterized at its base by *Perisphinctes tizianiformis* Choffat and other upper Oxfordian-Sequanian ammonites and at its top by forms of the *tenuilobatus* zone, was designated by Choffat as the Lusitanian, which accordingly comprises the upper Oxfordian, Sequanian, and lower Kimmeridgian stages. The term Lusitanian is, in other words, a comprehensive one often representing a discontinuous section cut by at least one unconformity and by an intra-Kimmeridgian regression period marked locally by intercalations of coarse polygenic detritus and cross-bedded sandstones and occasionally even by coal-bearing beds (Mempel, 1955; Oertel, 1956; Schott and Staesche, 1957).

For the overlying deposits containing *Lima pseudoalternicosta* Buvignier, *Pterocera oceani* (Brongniart), *Perna rugosa* (Muenster), etc., the term "Ptérocerin" was used by Choffat. With the name "Freixialin," derived from the town of Freixial, about 10 km. west of Alverca, Choffat designated the uppermost Jurassic beds ("Portlandian" of authors = ?Tithonian of Arkell, 1956), which largely carry the same fauna as the underlying "Ptérocerin" (= Kimmeridgian). According to Choffat (1901, p. 129), this limestone complex, roughly 100 meters in thickness, is intercalated between the "Ptérocerin" with *Perisphinctes*, *Oppelia*, *Lithacoceras*, *Pterocera oceani* (Brongniart), *Natica gigas* Strombeck, *Mytilus morrisi* Sharpe, etc., and the basal Cretaceous. The "Freixialin" was reported as still containing *Pterocera oceani*, *Natica gigas*, *Lucina rugosa* (Roemer), etc., as well as "*Dicyclina*" *lusitanica*. Strangely enough, the smaller form ("*Spirocyclina infravalanginiensis*") was not recorded at all by Choffat from Cape Espichel, although several such tests less than 2 mm. in diameter are attached to some of the large discoid specimens (pl. 2, figs. 11–12) in the original collection of Choffat.

In the Torres Vedras area, the "Freixialin" also contains Kimmeridgian elements such as *Mytilus morrisi* Sharpe, *Astarte discus* Sharpe, *Lucina rugosa* de Loriol, *Cyprina securiformis* Sharpe, etc. Among the new forms, *Trigonia freixialensis* Choffat, *Trigonia kobyi* Choffat, *Gervilleia lorioli* Choffat, and "*Spirocyclina choffati* Munier-Chalmas var. *lusitanica* Choffat" may be cited (Zbyszewski and d'Almeida, 1955,

p. 16). The published *Iberina*-bearing localities within the Upper Jurassic of the Torres Vedras basin include S. Domingos da Fanga da Fé, Gradil, Vila Franco do Rosario, Sto. Aleixo, Freixial, and Arsena (Alverca).

The "Ptérocerin" (Kimmeridgian) harbors an identical molluscan fauna, including *Lima pseudoalternicosta* Buvignier, *Pterocera oceani* (Brongniart), *Natica gigas* Strombeck, *Natica hemisphaerica* Roemer, *Mytilus morrisi* Sharpe, *Perna rugosa* (Muenster), etc. This complex overlies fossiliferous upper Lusitanian beds carrying diagnostic ammonite markers such as *Streblites tenuilobatus* (Oppel), *Taramelliceras trachynotum* (Oppel), *Lithacoceras unicomptum* (Fontannes), etc., which permit correlation with the lower Kimmeridgian *tenuilobatus* "zone." The underlying Montejunto beds are upper Oxfordian in age (*Epipeltoceras bimammatum*, *Ochetoceras canaliculatum*, *Orthosphinctes polygyratus*, etc.).

The Upper Jurassic-Lower Cretaceous section along the southern flank of the Serra de Sintra is discussed in a modern summary by Zbyszewski (1955, pp. 26–28). The igneous rocks are overlain by a Lusitanian limestone complex up to 1000 meters in thickness, which carries *Perisphinctes*, *Oppelia*, *Haploceras*, etc.; the presence of *Phylloceras silenus* Fontannes suggests a Sequanian-lower Kimmeridgian age. The overlying marly and coralline limestones, placed in the Lusitanian-Kimmeridgian, contain *Lima pseudoalternicosta* Buvignier and *Perisphinctes ribeiroi* Choffat. The succeeding concretionary limestone is reported to carry *Pterocera oceani* (Brongniart), *Lucina rugosa* (Roemer), *Unicardium crassum* Choffat, *Astarte discus* Sharpe, *Pinna occidentalis* Choffat, *Mytilus morrisi* Sharpe, etc., and, in its upper part, *Trigonia freixialensis* Choffat, *Corbicella barrensis* Buvignier, *Aptyxis*, *Cyrena*, and "*Spirocyclina choffati* Munier-Chalmas var. *lusitanica* Choffat" (Zbyszewski, 1955, p. 27). *Lucina rugosa*, *Unicardium crassum*, *Astarte discus*, *Mytilus morrisi*, and *Trigonia freixialensis* are forms known from the Kimmeridgian and "Freixialin" ("Portlandian" of authors) of Cape Espichel and of the Torres Vedras area, but are of little value for exact age determination. *Pterocera oceani*, on the other hand, is a typical species of the lower Kimmeridgian (*tenuilobatus* "zone"), which also characterizes the "Ptérocerin" (lower Kimmeridgian) and "Freixialin" of Cape Espichel.

In the Sintra region, *Iberina* is recorded from the Intravalanginian of Olelas, Sabugo, and Brouco, and from the marly limestones that underlie the Infravalanginian beds with *Natica leviathan* Pictet and Campiche at Forte do Guincho, Charneca, Murches, etc. In the area of Loulé-San João,

Algarve (southern Portugal), the "Ptérocerin" with some perisphinctids is reported to carry also *Pterocera* cf. *oceani*, *Lucina rugosa*, and *Astarte discus*, as well as *Exogyra* cf. *bruntrutana* (Thurmann), *Pholadomya hemicardia* Roemer, *Diceras suprajurensis* Thurmann, *Pseudocidaris thurmanni* Agassiz, etc. The last-named species is a diagnostic marker of the basal Kimmeridgian. Among the *Iberina*-bearing localities of Algarve, we may mention Zavial, Luz, Almadena, Loulé-S. João, and Tavira-Fuzeta.

The "Ptérocerin" and "Freixialin" of Choffat thus correlate largely with the lower Kimmeridgian (in the sense of Arkell, 1956). From a micropaleontological viewpoint, the samples examined from the "Portlandian" of Cape Espichel, Gradil, etc., also indicate a lower Kimmeridgian age: The presence of *Pseudocyclammina jaccardi* (Schrodt) (*Pseudocyclammina sequana*), *Ammobaculites coprolithiformis sequana* Mohler, etc., in some of the samples that also contain *Iberina lusitanica* ("*Dicyclina*" *lusitanica* and "*Spirocyclina infravalanginiensis*") clearly shows that these beds cannot be younger than lower Kimmeridgian. "*Pseudocyclammina*" *virguliana* (Koechlin), a diagnostic form that extends from the lower Kimmeridgian into the base of the middle Kimmeridgian (*gigas* zone) occurs together with small specimens of *Pseudocyclammina* sp. in the stratigraphically highest sample available from the section at Cape Espichel. It is therefore concluded that the *Iberina*-bearing beds of Cape Espichel represent the lower Kimmeridgian in the sense of Arkell (1956).

This age determination finds great support in the association of ostracodes, which were identified by Dr. H. Oertli, of Chambourcy. All of the samples that contain *Iberina lusitanica* also contain *Cytherella suprajurassica* Oertli, a characteristic species of the lower Kimmeridgian (lower and middle portions) of the Swiss Jura Mountains and of northern Germany. In the Paris Basin, this species shows its optimum development in the lower Kimmeridgian; a few scattered specimens occur as early as the Oxfordian, and the form disappears in the upper part of the lower Kimmeridgian (Pterocerian). Another species, *Cytherelloidea weberi* Steghaus, which also occurs in the samples studied from Cape Espichel, is restricted to the middle part of the lower Kimmeridgian (Oertli, 1957). Accordingly, it is evident that the term "Portlandian," customarily used since the time of Choffat to designate the beds of the uppermost Jurassic section at Cape Espichel and in the entire Lusitanian trough, is a conventional denomination and does not represent the equivalent of the stratigraphically higher Portlandian (Portland beds proper).

The beds with *Iberina lusitanica* ("*Spirocyclina infravalanginiensis*") somewhat arbitrarily referred to the Infravalanginian cannot be dated exactly by the faunal evidence given by Choffat, and the character of the deposits does not change from the Upper Jurassic to the supposed Infravalanginian. Although the large discoid form of *Iberina* is held to be particularly characteristic of the Upper Jurassic (Choffat, 1887, p. 310; 1901, p. 112; Schlumberger and Choffat, 1904, p. 367), certain horizons of the "Portlandian" (Algarve) are stated to be composed of small tests of *Iberina* ("*Spirocyclina infravalanginiensis*"). In the Serra de Sintra, the "*Spirocyclina*"-bearing marls are reported to succeed the Portlandian, and are followed above by a limestone with "*Dicyclina lusitanica*" and *Cyprina infravalanginiensis* Choffat (Choffat, 1901, p. 139). East of Sintra (Olelas, Brouco), on the other hand, 66 meters of "Portlandian" beds are reported to carry large specimens of *Iberina* ("*Dicyclina lusitanica*"), and the strata with smaller tests of *Iberina* ("*Spirocyclina infravalanginiensis*"), 65 meters in thickness and assigned to the Infravalanginian, are separated from the lower *Iberina* level by 23 meters of identical rocks in which *Iberina* is absent (Choffat, 1901, p. 125; Schlumberger and Choffat, 1904, p. 365). Tests of the small form "*infravalanginiensis*" are attached to a number of large discoid specimens of *Iberina lusitanica* (Choffat collection, Lisbon) from the Infravalanginian of Forte do Guincho and Pisão (pl. 2, figs. 11–12, 14). In the Infravalanginian near Luz, Algarve, the very common small forms of *Iberina* are associated with large specimens of "*Dicyclina*" (Choffat, 1887, p. 276; 1904, p. 366), and the same association is also recognized in the samples available from Cape Espichel, which are definitely of Upper Jurassic (lower Kimmeridgian) age.

These examples thus indicate that the occurrence of "*Dicyclina*" *lusitanica* and "*Spirocyclina*" *infravalanginiensis* is certainly not due to chronological factors, and no stratigraphic significance can be attributed to either of them. This inconstancy in the stratigraphic order of these forms of *Iberina* is not to be wondered at, since it is now realized that they are not different species or subspecies but generations of one and the same specific unit (*Iberina lusitanica*).

We also feel that the attribution of certain strata to the Infravalanginian is not based solidly enough on paleontological evidence to be accepted without reservation. Choffat's principal reason for referring certain beds with "*Dicyclina*" and "*Spirocyclina*" to the Infravalanginian is their association with *Trigonia caudata* Agassiz, a Lower Cretaceous species (Choffat, 1901, p. 140). Since these marine beds may

be overlain by true Infravalanginian beds with *Natica leviathan* (placed by Choffat in the Valanginian) (Choffat, 1885, p. 114), their age might well still be uppermost Jurassic. In his paper on the Cretaceous of the Arrábida, Choffat himself stated, with regard to the section at Cape Espichel (Lagosteiros): "On manque de critérium pour placer la limite entre les deux systèmes" (Choffat, 1904, p. 5), and with respect to the area of Ericeira: "Je ne connais pas le banc qui doit être considéré comme limite du Jurassique" (op. cit., p. 24). Concerning eastern Algarve, he stated: "On ne voit pas les rapports de l'Infravalanginien avec les couches sous-jacentes, ni avec celles qui les recouvrent" (Choffat, 1887, p. 276).

In addition to *Iberina lusitanica*, the Infravalanginian beds are reported to carry *Cyprina infravalanginiensis* Choffat, *Corbula* cf. *inflexa* Roemer, *Trigonia caudata* Agassiz, and *Cyrena*, as well as some gastropods (*Aptyxis*, *Cerithium*, etc.). A basal limestone carries *Trigonia caudata*, a species of great vertical range (Valanginian to Cenomanian), and the fauna of the succeeding marly limestone includes *Nerinea (Aptyxis) infravalanginiensis* Choffat, *Nerinea douvillei* Choffat, *Tylostoma laharpei* Pictet and Campiche, *Natica pidanceti* Coquand, *Natica pilleti* Choffat, *Cyprina infravalanginiensis* Choffat, etc., as well as "*Spirocyclina choffati* Munier-Chalmas var. *infravalanginiensis* Choffat" (Zbyszewski, 1955, p. 26). Some of these forms are also represented in the overlying marly limestone (100 meters), which, moreover, contains *Natica leviathan* Pictet and Campiche, *Natica mexilhoeirensis* Choffat, *Natica laevigata* d'Orbigny, *Thracia nicoleti* Agassiz, *Cyprina valanginiensis* Pictet and Campiche, etc. This complex is correlated with the Valanginian, but the presence of the diagnostic species *Natica leviathan* indicates rather an Infravalanginian (Berriasian) age.

Thanks to the courtesy of Mobil Exploration Portugal Inc., Lisbon, the author was able to examine several foraminiferal slides from their well Barreiro no. 1, located about 10 km. southeast of Lisbon. *Iberina lusitanica* could be identified in only one sample, which is referred to as "Valanginian." According to Gentil Ferreira, paleontologist of Mobil Exploration Portugal, this conventional term also includes the Infravalanginian of Choffat, which, as pointed out previously, may also include the uppermost Jurassic.

In the Lusitanian basin of Portugal, which is bounded on the northeast by the Hercynian High of the Iberian Meseta, *Iberina* thus occurs abundantly in the lower Kimmeridgian, up to a horizon below the Infravalanginian beds with *Natica leviathan* (see

pl. 2; pl. 3, figs. 1, 11; pl. 4; pl. 5, figs. 1–4; pl. 7, figs. 1–4; pl. 8, figs. 4–11). This Lusitanian trough formed part of the Tethys sea (marginal regions), which also covered large areas of North Africa (Tellian and Saharan Atlas Mountains north of Hercynian Africa of the Sahara Plateau).

Spain

Numerous specimens of "*Spirocyclina infravalanginiensis* Choffat" were found at Ramales, Province of Santander (Rat, 1955, pp. 1820–1821). The tests which we received from Rat for study all represent the A-1 form of *Iberina lusitanica* (pl. 7, fig. 8). They were derived from a thick detrital series that is intercalated between the *Macrocephalites*-bearing Callovian and the Aptian with *Orbitolina*. This detrital formation attains a thickness up to 800 meters, and its upper half has been compared with the Wealden facies of the late Jurassic and Infravalanginian. *Iberina lusitanica* is present in the lower 150–200 meters in a level which is believed to represent either upper Portlandian or basal Valanginian (Rat, 1955). The beds with *Iberina* are reported to carry *Serpula*, gastropods, and the ostracode species *Macrodentina retirugata* Jones (listed as *Dictyocythere retirugata* by Rat in a recent letter). This last-mentioned form is known from the Portlandian Swindon series, as well as from the Purbeck beds of Buckinghamshire. The thin sections of "*Spirocyclina* cf. *infravalanginiensis* Choffat" figured from the Tithonian of Cuber, Mallorca, Balearic Islands (Colom, 1947, pl. 14, figs. 1–2), which Colom very kindly placed at the writer's disposal for examination, cannot be referred to *Spirocyclina* or *Iberina* (absence of an alveolar subepidermal layer).

North Africa

In late Jurassic and early Cretaceous time, the Tethys sea covered a large area north of the African Shield, from the Atlantic coast across Morocco, Algeria, Tunisia, Tripolitania, etc., to the Middle East. In the south, this mesogean sea was bounded by a variscan landmass, the present-day Sahara Plateau.

Morocco: The few samples which could be examined from the Mogador region carry an abundance of *Pseudocyclammina jaccardi* (Schrodt), but *Iberina* is not represented.

Algeria: In the western portion of the Tellian Atlas, *Iberina* ("*Spirocyclina choffati* var. *infravalanginiensis*") is reported to occur beneath beds with *Natica leviathan* (Dalloni, 1952, p. 64). The same foraminifer

is listed from Djebel Zenine at the Algerian-Moroccan border (Lucas, 1942, p. 390). According to that author, it occurs in a few horizons of the upper sublithographic limestones, associated with rare *Calpionella*; megalospheric and microspheric tests are reported occasionally to constitute certain rocks of the section (loc. cit., p. 396). In a recent summary, Lucas (1952, p. 63) listed these forms from the Portlandian of Oran as "*Spirocyclina (Choffatella) choffati* var. *infravalanginiensis*," and the "*Spirocyclina*" from the Tiaret region were interpreted as "*Pseudocyclammina* ou *Choffatella*" (ibid., p. 104). Photomicrographs of some of the thin sections in the Lucas collection (Djebel Zenine), as well as the examination of samples from the same region and farther eastward (Tlemcen, Tiaret, etc.), show, however, that we are here dealing with representatives of true *Iberina lusitanica*.

In the Tlemcen Mountains, the *Iberina* horizon is underlain by a limestone complex conventionally assigned to the Portlandian, which carries *Mytilus* cf. *jurensis* Merian, *Perna rugosa* Sowerby, *Astarte* cf. *supracorallina* d'Orbigny, etc. *Natica leviathan* Pictet and Campiche has also been found in the vicinity (Lucas, 1942, p. 402). This fauna suggests a Kimmeridgian age, but *Natica leviathan* points to basal Valanginian.

Farther to the northeast, in the Tiaret region (Tagdempt), the beds carrying *Iberina lusitanica* (pl. 6, fig. 7; pl. 7, figs. 10, 13) contain *Pterocera oceani* (Brongniart), *Natica hemisphaerica* Roemer, and *Ostrea cyprea* d'Orbigny, and are dated as Kimmeridgian (Welsch, 1890, p. 39; Lucas, 1952, p. 104). A rock specimen deposited in the collection of the Museum of Natural History, Paris (Le Mesle collection), is labeled "*Spirocyclina* sp., Kimmeridgien, Tagdempt (Oran)"; this limestone is composed exclusively of non-oriented tests of *Iberina lusitanica* (megalospheric forms). In a recent paper, "*Spirocyclina choffati* var. *infravalanginiensis*" was listed from Tagdempt (Dalloni, 1952, p. 64).

The *Iberina*-bearing horizon is reported to be underlain by fossiliferous beds which are also of lower Kimmeridgian age, since they contain, among others, *Cidaris glandifera* Muenster, *Terebratula bicanaliculata* Schlotheim, *Rhynchonella inconstans* Sowerby, and *Rhynchonella pinguis* Roemer. The samples that we were able to study from the area southwest of Tiaret carry abundant specimens of *Iberina lusitanica* and *Clypeina jurassica* Favre and Richard.

At Djebel Nador de Trezel, southeast of Tiaret, the *Iberina* horizon occurs above lower Kimmeridgian beds that carry *Clypeina, Pseudocyclammina jaccardi*

(Schrodt), etc. Sigal had previously identified "*Cyclammina* n. sp., *Cyclammina sequana* var. *minor* Mohler, *Cyclammina sequana* aff. var. *minor* Mohler, *Choffatella personata* Tobler, *Pseudocyclammina lituus* Yokoyama, and *Cyclammina jaccardi* Schrodt" from that locality (see Karpoff, 1950, pp. 236–237).

In the southern Atlas range (Saharan Atlas), south-southeast of Algiers in the region of the Oulad Naïl Mountains, the *Iberina* horizons ("*Spirocyclina choffati* Munier-Chalmas") are not accurately datable. According to published sources, *Iberina* has been found at Djebel Zerga in association with *Clypeina, Pseudocyclammina* cf. *sequana* (Merian) var. *minor* Mohler, *Choffatella* sp., *Nautiloculina* cf. *oolithica* Mohler, *Trocholina* sp., etc. (Emberger, 1955b, p. 544); the reported presence of *Pterocera oceani* is suggestive of a lower Kimmeridgian age. The material examined from that locality, where *Iberina lusitanica* is locally very common (pl. 5, fig. 9; pl. 8, fig. 13), has yielded no new clue to the age of this horizon. A number of compressed tests in this community, externally resembling *Choffatella* or *Pseudocyclammina jaccardi personata*, show an internal organization intermediate between *Pseudocyclammina* and *Iberina*; whereas the arcuate chambers are undivided throughout in *Choffatella* and *Pseudocyclammina*, the form in question sporadically shows some interseptal buttresses which align the different chambers, a feature which is particularly well developed in *Iberina*. In certain specimens, the zone of open chambers (zone 2) is broader at the expense of the central labyrinthic zone (longer duration of the *Choffatella* stage). Sigal, who sent the writer some of these specimens from the Upper Jurassic of Djebel Nador de Trezel years ago, denominated them (in litt.) "formes de passage de *Choffatella* à *Spirocyclina*." Because of the fact that these tests display a truly cribate aperture, however, they are intermediate between *Pseudocyclammina* and *Iberina*.

At Djebel Zireg (Meharga), south of Chott El Hodna, the Upper Jurassic stromatoporoid limestones with *Clypeina jurassica* and "*Spirocyclina choffati* Munier-Chalmas" are reported to be overlain by beds with abundant foraminifera, from which Magné (S.N.REPAL, Algiers) has identified "*Pseudocyclammina personata* Tobler, *Choffatella* aff. *peneropliformis* Yabe and Hanzawa, *Eoguttulina* aff. *anglica* Cushman and Ozawa, *Lituola* cf. *siemiradzkii* Cushman and Glazewski, *Lituola* cf. *bukowiensis* Cushman and Glazewski, *Ammomarginulina* cf. *fontinensis* Franke," etc. These beds are followed above by limestones with *Calpionella alpina* Lorenz, *Calpionella elliptica* Cadisch, *Tintinnopsella carpathica* (Murgeanu and Filipescu), etc., which have been referred to the

upper Berriasian (Emberger, 1955b, p. 545; Emberger and Magné, 1956, p. 190). The fossiliferous material examined from the section at Djebel Zireg, which we received from Magné, is correlated with the Kimmeridgian and Infravalanginian. All the foraminiferal samples taken between the top of the stromatoporoid limestone with *Clypeina jurassica* and the dolomites of Valanginian age (Magné, *in litt.*) contain a great abundance of larger and smaller specimens of *Iberina lusitanica*. *Pseudocyclammina jaccardi personata*, a form largely of lower Kimmeridgian age, occurs only in the basal portion but is not represented in the higher foraminiferal beds, where *Pseudocyclammina lituus* (Yokoyama) appears; all the compressed forms, which, from an external point of view, might be referable to *Pseudocyclammina personata*, clearly manifest the internal structure of *Iberina lusitanica*. Some other tests resembling *Pseudocyclammina personata* reveal the development of some irregular interseptal projections in the central portion (*Iberina* type); this undescribed transitional form was also observed in the Kimmeridgian of the Tiaret area, as stated previously.

In the upper part of the foraminiferal beds of Djebel Zireg, *Iberina lusitanica* (pl. 3, figs. 4–5, 12; pl. 6, figs. 4–5; pl. 7, figs. 11, 14) is associated with rare specimens of *Choffatella* cf. *peneropliformis* and with typical representatives of "*Pseudocyclammina*" *virguliana* (Koechlin), a diagnostic form which is widely distributed in the entire lower Kimmeridgian and which reaches the lowermost part of the middle Kimmeridgian (interpretation of Arkell, 1956 = lower Portlandian of authors). *Choffatella peneropliformis* Yabe and Hanzawa is a little-known form occurring in the Torinosu limestone of Japan (mainly lower Kimmeridgian). Isolated tests of this species were recently found by the writer in the lower Kimmeridgian of Cape Espichel, Portugal.

The other forms listed by Magné cannot throw any light on the age of the *Iberina* assemblage. *Pseudocyclammina siemiradzkii* and *Pseudocyclammina bukowiensis* are species known from the supposed Portlandian of Nizniow on the Dniestr River, Poland. *Ammobaculites fontinensis* (Terquem) Franke, originally described from the Lower Jurassic, is a nondiagnostic species, as it has been greatly expanded in the course of time and now includes Cretaceous and even Recent forms. *Eoguttulina anglica* is a species recorded from the Aptian-Albian of England, which also occurs in the upper Albian Washita group of North America.

This horizon of the Kimmeridgian is reported to be succeeded by *Calpionella*-bearing limestones con-

taining *Calpionella alpina* Lorenz, *Calpionella elliptica* Cadisch, and *Tintinnopsella carpathica* (Murgeanu and Filipescu), forms which in stratigraphically higher levels are accompanied by *Tintinnopsella* aff. *longa* (Colom), *Stenosemellopsis hispanica* (Colom), *Calpionellopsis thalmanni* (Colom), *Globochaete alpina* Lombard, etc. (Emberger and Magné, 1956, p. 190). *Calpionella alpina* and *Calpionella elliptica* are late Jurassic (middle and upper Tithonian) species, which may extend into the basal Berriasian; *Tintinnopsella carpathica*, originally described from the Carpathian Tithonian, is a diagnostic Neocomian form that attains the base of the Barremian. Accordingly, the age of the lowermost part of the *Calpionella*-bearing limestones is not younger than Berriasian.

In the uppermost beds of the same section, in a sample underlying the Valanginian dolomites, the rich *Iberina lusitanica* population (pl. 6, fig. 3; pl. 7, fig. 12; pl. 8, figs. 12, 15; text-fig. 3d) is accompanied only by *Clypeina* and some specimens of *Pseudocyclammina* aff. *lituus* (Yokoyama). Other forms reported to occur here include *Trocholina elongata* (Leupold) and *Trocholina burgeri* Emberger, the former being a species of wide vertical range (Upper Jurassic to Lower Cretaceous), and the latter a form recently established on this material from Djebel Zireg (Emberger, 1955a). A Valanginian age is, however, suggested by the presence of an ammonite determined as *Kilianella* sp. (Emberger, loc. cit.).

According to Magné, this Neocomian fauna corresponds to the level of *Choffatella zireggensis* Sigal, a form described from a single locality at Djebel Zireg (Sigal, 1952, pp. 12–13). This zone, originally placed in the Hauterivian (Sigal) and now referred to the Berriasian-Valanginian (Magné), contains a great abundance of "*Choffatella*" *zireggensis*, the attribution of which to the genus *Choffatella* has been questioned by the writer (Maync, 1955, pp. 269–270). A thorough first-hand study, based on a rich and beautifully preserved assemblage received from Magné, has now revealed that this form is identical with *Iberina lusitanica* (pl. 3, figs. 2–3, 6–7, 10; pl. 5, figs. 7–8; pl. 6, fig. 6; pl. 8, figs. 1–3); even the peneropline tests that resemble *Choffatella* externally disclose the internal structure of *Iberina* throughout. Sigal (1952, p. 13) had already pointed out that a number of specimens of "*Choffatella zireggensis*" grade into *Anchispirocyclina*. The section at Djebel Zireg (Meharga) thus reveals that *Iberina lusitanica* is not a stratigraphically restricted species, as it appears in the lower Kimmeridgian and is still abundantly represented in beds of probably lower Valanginian age.

At Fennd Guelalia, northeast of Djebel Zireg, *Iberina lusitanica* was found near the base of a limestone complex carrying *Pterocera* cf. *oceani* (Brongniart); *Clypeina* occurs in great numbers immediately above this *Iberina* level of the Kimmeridgian (Emberger, 1955b). Thin sections containing large numbers of *Iberina lusitanica* ("*Anchispirocyclina*") from the Taguine water well (S.C.H.), located in the same area, were kindly placed at the writer's disposal by Lacassagne (C.F.P., Paris). On the basis of stratigraphic considerations, this sample has been assigned a "Neocomian" age.

Tunisia: A Kimmeridgian age may safely be assumed for a core sample from Chott Fedjadi well no. 1, east of El Hamma, Tunisia, which the author received from Glintzboeckel (S.E.R.E.P.T., Tunis) for examination. This sample was derived from the uppermost 50 meters of the Jurassic limestone complex (below the "Wealden" sands), and contains *Iberina lusitanica* as well as *Pseudocyclammina jaccardi personata* and "*Pseudocyclammina*" *virguliana* (Koechlin).

Arabia

The *Iberina*-bearing horizon ("*Spirocyclina* sp.") recorded in Dukhan wells no. 1, 2, and 3, Qatar Peninsula, occurs in an Upper Jurassic limestone containing *Procerithium hunti* Cox, *Exogyra nana* (Sowerby), *Lithodomus* cf. *lorioli* Krumbeck, and *Cladocoropsis* sp. (Henson, 1948, p. 20). This assemblage is scarcely adequate for establishing the age of *Iberina* in Arabia. *Exogyra nana* is a species that extends from the basal Kimmeridgian (*cymodoce* zone) into the Portlandian; *Procerithium hunti*, a "Portlandian" species, was found 250 feet above "*Pseudocyclammina*" *kelleri* (Henson) in Dukhan well no. 1, and *Pseudocyclammina lituus* (Yokoyama), assigned to the Valanginian, occurs 200 feet above the highest Upper Jurassic fossil horizon with *Cladocoropsis* sp. (Henson, 1948, pp. 15–17). It may be stressed that the widely distributed *Cladocoropsis* limestone of the Tethys region is generally regarded as lower Kimmeridgian (Arkell, 1956, p. 195). In Greece, for example, this *Cladocoropsis* limestone also carries *Pseudocyclammina jaccardi personata*, "*Pseudocyclammina*" *virguliana*, *Conicospirillina basiliensis*, etc. (Renz and Reichel, 1950), or, in other words, a lower Kimmeridgian faunule.

Turkey

The age of the beds at Zonguldak in northern Anatolia, on the coast of the Black Sea, where *Iberina lusitanica* occurs both as large tests up to 11 mm. in diameter (pl. 5, figs. 5–6) and as small coiled ones, cannot be precisely established. The Mesozoic limestones, 100–200 meters in thickness, transgress with

a basal conglomerate on the Paleozoic, and the *Iberina* level ("*Spirocyclina choffati euxina* Charles"), merely a few centimeters in thickness, occurs only in the upper portion of the limestone, being associated with some *Chara* oogonia. The limestone is succeeded by a thick conglomerate and flysch complex of supposed Neocomian age, and higher by an Urgonian limestone with *Orbitolina*. The Zonguldak outcrop is therefore pre-Barremian in age, and has been assigned to either the Portlandian or the Valanginian (Charles, 1932, 1933, 1954).

Yugoslavia

The surface samples studied from Repište, near Belgrade, which are believed to represent the Jurassic-Lower Cretaceous boundary or, on the basis of the ostracodes, the Valanginian-Hauterivian (Wicher, *in litt.*), contain beautifully preserved specimens of *Iberina lusitanica* (pl. 3, figs. 8–9; pl. 6, fig. 1; pl. 7, figs. 6–7), which were identified as *Choffatella decipiens* Schlumberger by Bronnimann (Wicher, *in litt.*). "*Pseudocyclammina*" *virguliana* (Koechlin), *Ammobaculites* cf. *coprolithiformis sequana* Mohler, *Triplasia* sp., etc., occur in association with *Iberina*. It is therefore believed that the outcrop at Repište is not younger than basal middle Kimmeridgian ("lowermost Portlandian" of authors). According to an oral communication by the late C. A. Wicher, of Hannover, the same form occurs on Avala Hill, near Belgrade, and at Senski Rudnik and Topčider.

Switzerland

The few specimens recorded as "*Spirocyclina infravalanginiensis* Choffat" from the Upper Jurassic and basal Cretaceous of the Swiss Alps (Maync, 1938, p. 64) are associated with *Pseudocyclammina lituus* (Yokoyama), *Choffatella peneropliformis* Yabe and Hanzawa, and *Trocholina alpina* (Leupold). The oblique section, no. 99, of *Iberina lusitanica* illustrated by Maync (1938, pl. 4, fig. 11 = pl. 8, fig. 14, of the present paper) is deposited in the Geological institute of the University of Bern, Switzerland. Exact determination of the age of the horizon with *Iberina lusitanica* is not yet possible.

France

The *Iberina* horizon identified in several wells drilled in the Paris Basin (C.E.P.) can be reliably dated. The first specimens were described from Beynes well no. 1 (101), west of Paris (Aurouze and Bizon, 1955), and the same horizon has since been encountered in the wells Courgent no. 1, Maule no. 1, Longuesse no. 1, Rambouillet no. 1, Dourdan no. 1, and Puiselet no. 1 (pl. 7, fig. 9). It occurs immediately below the Wealden sand and above the beds

characterized by a great number of Lituolidae, such as "*Pseudocyclammina*" *virguliana*, "*Ammobaculites-Haplophragmium*," etc., of early middle Kimmeridgian age. *Pseudocyclammina jaccardi personata* Tobler and *Pseudocyclammina jaccardi* (Schrodt), of the lower Kimmeridgian, come in at a slightly lower level. The Upper Jurassic mollusk fauna recorded from the Beynes structure (Aurouze and Bizon, 1955, p. 52) is too unrestricted to permit a macropaleontological age determination. The ostracode faunas, however, which have been studied by Oertli in the Paris Basin, furnish more exact data, as they include some characteristic species. *Limnocythere inflata* Steghaus, a form that has a wide vertical range (upper part of the lower Kimmeridgian to Portlandian), is still represented 10 meters above the *Iberina* level in Dourdan well no. 1. A similar stratigraphic range can be attributed to "*Macrodentina*" *ornata* (Steghaus). *Macrodentina* n. sp. of Oertli (1957, p. 670) is a diagnostic form restricted to the lower portion of the middle Kimmeridgian (to be described as *Macrodentina (Macrodentina) annulata* Malz, 1958). In association with the common "*Pseudocyclammina*" *virguliana* — "*Ammobaculites*" population, this species was found in several wells 45–65 meters below the *Iberina* horizon. In Beynes well no. 101, this middle Kimmeridgian species was still present 6 meters below the base of the horizon with *Iberina lusitanica*. *Macrodentina (Macrodentina) sculpta* Klingler, which seems to be restricted to the middle Kimmeridgian in the Paris Basin, occurs in Longuesse well no. 1 in association with *Iberina lusitanica*.

It is thus evident that the *Iberina* horizon identified in the Paris Basin can be dated as middle Kimmeridgian. Such an age is supported by the presence of "*Pseudocyclammina*" *virguliana* and related forms, which to date are not known from strata younger than basal middle Kimmeridgian. In the Paris Basin, this lituolid community still persists above the top of the range of *Macrodentina* n. sp. of Oertli (1957), and accompanies *Iberina lusitanica* in Courgent well no. 1.

In the Aquitaine Basin of western France, *Iberina lusitanica* ("*Spirocyclina infravalanginiensis* Schlumberger") has been found to date only in the deep wells of the Parentis area, where drilling has extended down to the Jurassic (Parentis wells no. 11, no. 14, no. 19, and others). The thin sections that the present writer was able to examine at first-hand, thanks to the courtesy of Esso REP, Bègles-Bordeaux, contain the smaller A-1 form, which lacks a cyclic adult stage, as well as the A-2 form. According to the zonation by Esso REP (Dalbiez and Séronie-Vivien, 1957, p. 38), the *Iberina* horizon occurs above

the Kimmeridgian "lituolid-bearing limestone" (with *"Pseudocyclammina" virguliana, Pseudocyclammina jaccardi*, and *Pseudocyclammina jaccardi personata*), which is succeeded by a limestone containing coarsely arenaceous lituolids (*"Haplophragmium suprajurassicum* Schwager"). This limestone is correlated with the *gigas* zone of the middle Kimmeridgian of Arkell (1956) (= lower Portlandian of authors). In some of the samples studied from Parentis well no. 19, however, *Iberina* is still accompanied by *"Pseudocyclammina" virguliana* and *"Haplophragmium suprajurassicum,"* as it is in Courgent well no. 1 in the Paris Basin, and the age of the *Iberina* assemblage is thus dated in both basins as middle Kimmeridgian (pl. 6, fig. 2; pl. 7, fig. 9).

Iberina lusitanica has also been found by the writer in a slightly recrystallized limestone at Houn Barrade, about 16 km. southeast of Oloron-Ste. Marie (Dept. Basses-Pyrénées). This sample from the north flank of the Pyrenees also contains *Pseudocyclammina* cf. *jaccardi, Pseudocyclammina* aff. *lituus*, and *Trocholina elongata*, and is placed in the Kimmeridgian.

"Spirocyclina choffati Schlumberger" was recently recorded from the classic Valanginian of southern France, at Mont-Rose, near Marseille (Marie and Mongin, 1957). Marie, who has compared these small tests of *"Spirocyclina"* with those from Portugal, kindly showed me some thin sections from horizons 13 and 15 of the "middle Valanginian" (Marie and Mongin, 1957, p. 404, etc.), from which *"Spirocyclina choffati"* had been identified. This determination, however, cannot be confirmed, as all the identifiable sections clearly display open chambers *(Pseudocyclammina* or *Choffatella)*.

In a rock sample from the Purbeckian of Étournelles on Mt. Salève (Haute-Savoie), which we received from the Museum of Natural History of Basel, Switzerland, Pfender had determined *"Spirocyclina* cf. *infravalanginiensis* Choffat" (Maync, 1958c). Although the available material is not sufficient for a thorough identification of the many different forms of lituolids, it can be stated that specimens of true *Iberina lusitanica* are present in some of the thin sections (pl. 7, fig. 5).

Cape Verde Archipelago

Iberina lusitanica (pl. 7, fig. 15) occurs in a slightly metamorphosed limestone at Ponta do Escorregadeiro, São Nicolau Island. This species, found in beds supposed to be of Lower Pliocene age, had been identified as *"Peneroplis* aff. *planatus* (Fichtel and Moll) var. *assunçãoi"* (Sousa Torres and Pires Soares, 1946, pl. 18, figs. 4–5; pl. 19, figs. 1–3), but was later

referred to *"Spirocyclina* sp." by the writer (Maync, 1950, p. 533). Having now studied specimens from all over the world, we place the form from São Nicolau Island in synonymy with *Iberina lusitanica* (Egger). In association with *Iberina* there also occur tests with open chambers (Sousa Torres and Pires Soares, 1946, pl. 19, fig. 1), which belong either to *Choffatella* Schlumberger or to *Pseudocyclammina* Yabe and Hanzawa.

Cuba

Iberina lusitanica (pl. 5, fig. 10) was found in a number of thin sections of the Quemado limestone (lower part of the Viñales limestone) from Las Villas Province (Station 463–464 (D–266–267) of Gravell; Atlantic Refining Company sample no. 105, and U.S.G.S. sample no. 14721, Cantera, 1 km. north of Zulueta). On the basis of its rich ammonite faunas, the Quemado limestone is correlated with the middle upper Portlandian (see Bronnimann, 1954, p. 263), that is, with the middle Tithonian (Arkell, 1956). The only microfossils observed in the available thin sections are *Trocholina alpina* (Leupold), *Trocholina elongata* (Leupold), and *Pseudocyclammina* sp. aff. *lituus*. From the Portlandian limestones of the same area, Bronnimann lists, moreover, *Calpionella alpina* Lorenz, *Calpionella elliptica* Cadisch, *Globochaete alpina* Lombard, *Clypeina jurassica* Favre and Richard, *Conicospirillina basiliensis* Mohler, *Nautiloculina oolithica* Mohler, *Pseudocyclammina* cf. *lituus* (Yokoyama), and some new forms of no diagnostic value (Bronnimann, 1954, 1955). In the Tethyan Province, *Calpionella alpina* is restricted to the middle and upper Tithonian, although it may occasionally attain the basal Berriasian; *Clypeina jurassica* usually appears in the Kimmeridgian, and may persist into the Infravalanginian-Valanginian.

United States

Up to the present time, the only known occurrence of *Iberina lusitanica* in the United States is at Cape Hatteras, North Carolina, in N. C. Esso well no. 1 (Hatteras Light well no. 1), where *Anchispirocyclina henbesti* Jordan and Applin was encountered in core at 9115–9116 feet (Swain, 1947; Jordan and Applin, 1952). This foraminifer was placed by the present author in synonymy with *"Spirocyclina"* of authors and *"Spirocyclina* aff. *infravalanginiensis* Choffat," respectively (Maync, 1956). Thin sections loaned by the U. S. Geological Survey (Paleontology and Stratigraphy Branch), Washington, fully support this identification, so that the form from North Carolina is now regarded as a junior synonym of *Iberina lusitanica* (pl. 5, fig. 11; pl. 6, figs. 8–10).

The material examined contains a large number of specimens of *Iberina lusitanica* (forms A–1, A–2, and B), but they are not accompanied by any other characteristic microfossils, so that the age of the *Iberina* horizon cannot be accurately dated. Swain, after having considered a Lower Cretaceous age, arrived at the conclusion that the bed is Upper Jurassic, on the basis of certain ostracodes. Correlation was proposed with the Schuler formation (upper part of the Cotton Valley group of the southern United States), which overlies the Bossier formation, mainly of lower Kimmeridgian age (with an *Idoceras-Glochiceras* fauna and *Exogyra virgula* Defrance). Since the overlying Hosston formation is Neocomian to Barremian in age, the Schuler represents, on the basis of stratigraphic considerations, the middle upper Kimmeridgian to Purbeckian (Tithonian) interval or a part of it.

Conclusion

The foregoing discussion demonstrates that *Iberina lusitanica* (Egger) has a rather great vertical range and cannot serve as a restricted stratigraphic marker; it extends from the lower Kimmeridgian (in the sense of Arkell, 1956) into the uppermost Jurassic, straddles the Jurassic-Lower Cretaceous boundary, and has even been recorded from the lower Valanginian (Algeria).

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ABSTRACT: *The suborder Cladocopa comprises three genera and about forty-one living species, which are worldwide in distribution. Most Recent species are limited to the coastal waters of northwestern Europe and the Mediterranean Sea. Fossil occurrences are limited to Europe, with the exception of four specimens found near the top of a North Atlantic sediment core. Large forms from the Paleozoic of Europe are referable to the family Leperditellidae rather than to the Cladocopa. Recent Cladocopa are found exclusively in waters of normal salinity, and seem to prefer water temperatures between 4° and 14° C. Although collected occasionally at depths of 1280 to 2600 meters, they are usually found in waters less than 500 meters deep. The geologic evidence indicates that the anterior shell concavity was a late acquisition and may be an adaptation permitting more efficient swimming. If so, this may enable the Cladocopa to compete more successfully, and thus may account for the relatively large number of species of Cladocopa existing at the present time. A new species of the genus* Polycope *from the Great Bahama Bank is described and figured. Important papers concerning Recent Cladocopa are included in the bibliography.*

Distribution of the ostracode suborder Cladocopa, and a new species from the Bahamas

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INTRODUCTION

The suborder Cladocopa was proposed in 1866 by G. O. Sars to include the genus *Polycope*, which is the type of the family Polycopidae, the only family in this suborder. In the year 1894 G. W. Müller added another genus, *Polycopsis*, to the family, and suppressed the suborder Cladocopa by placing the family Polycopidae under the suborder Myodocopa. Skogsberg (1920, p. 158) concurred with Sars and retained the separate suborder, but used a different name, Polycopiformes, for it. Klie, in 1936, added the genus *Parapolycope* to the same family and presented additional evidence for maintaining the suborder. The writer concurs with Sars and Klie.

Recent Cladocopa are characterized by having a small oval shell, with or without a very slight anterior concavity. The valves are generally thin and translucent and are not strongly calcified. The male is usually slightly smaller than the female. Cladocopa differ from the members of all other ostracode suborders in having biramous second antennae on which the endopodite and exopodite are similar in size and are each provided with long setae. The left lamella of the male caudal furca usually contains fewer claws than the right and also adjoins the copulatory organ.
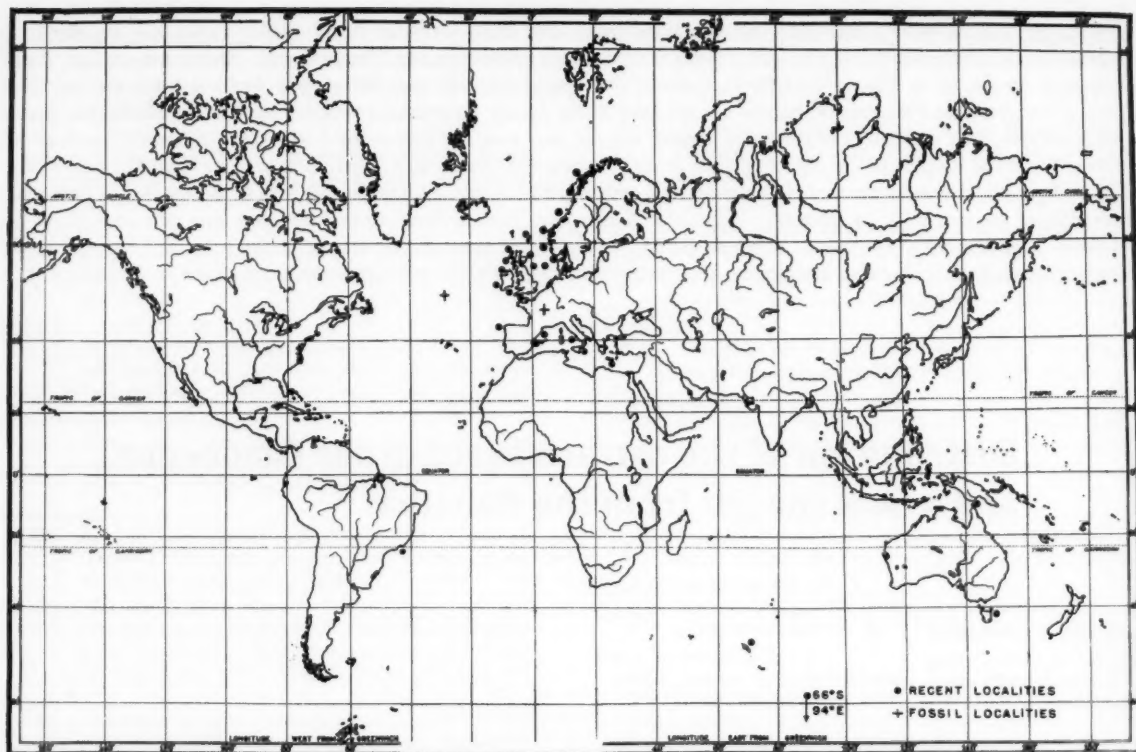
DISTRIBUTION OF LIVING CLADOCOPA

The Cladocopa are represented in their greatest diversity and abundance in the coastal waters of Europe (text-fig. 1), but this finding may be merely a consequence of the relatively thorough studies made in this area. Representatives have also been reported from widely separated localities, such as Antarctica (G. W. Müller, 1908), Tasmania (Chapman, 1919), Torres Straits (G. S. Brady, 1880), the Kerguelen Islands (G. S. Brady, 1880), Davis Strait, Greenland (Norman, 1877), Franz-Josef Land (Scott, 1899), the Cape of Good Hope (G. S. Brady, 1880), off the coast of Brazil (Hartmann, 1954), in the northwest portion of the Gulf of Mexico (Tressler, 1954), and in mud lumps collected from the Mississippi delta (H. V. Andersen, written communication, 1958).

DISTRIBUTION AND CLASSIFICATION OF FOSSIL CLADOCOPA

Cladocopa are known with certainty from the Recent and Pleistocene. They have also been recorded from the Cretaceous, Jurassic, Carboniferous, and Devonian. Some of these records are subject to question.

Polycope orbicularis G. O. Sars is the only known Pleistocene species. It is a common form living in

TEXT-FIGURE 1

DISTRIBUTION OF THE OSTRACODE SUBORDER CLADOCOPA

the seas around northeastern Europe, and is present but less abundant elsewhere. Fossil specimens have also been collected from glacial and post-glacial beds at many localities in Scotland (Brady, Crosskey, and Robertson, 1874), and four specimens were found 0.5 meter below the top of sediment core obtained from the top of the "Faraday Hills," a narrow part of the mid-Atlantic ridge (Tressler, 1942).

Moore (1878) listed, without figures or description, a *Polycope* sp.(?) from the Cretaceous of England. Whether this record is correct or not is a matter of uncertainty.

The species reported by Terquem (1885, 1886) from the Jurassic of France possibly belong to the Cladocopa. They lack the slight anterior sinus characteristic of most Recent species, but their size-range is consistent with the group.

Polycope burrovii Jones, Kirkby and Brady, *Polycope simplex* (Jones and Kirkby), and *Polycope youngiana* (Jones and Kirkby) have been recorded from the Carboniferous of the British Isles. *Polycope devonica*

Jones, *Polycope devonica concinna* Whidborne, *Polycope devonica major* Whidborne, *Polycope devonica obliqua* Whidborne, and *Polycope hughesiae* Whidborne have been recorded from the Devonian of England. These species probably do not belong to the Cladocopa, because of their very large size (see text-fig. 2). It is the writer's opinion that these Paleozoic forms probably belong to the Paleozoic family Leperditellidae.

The species reported by Rzehak (1910) from the Devonian of Moravia (*Polycope clymeniarum* Rzehak and *Polycope* sp.) are too elongate to belong to the suborder Cladocopa, and for this reason their measurements have been excluded from text-figure 2. The shell lengths reported by Rzehak for these species range from 0.75 to 1.5 mm.

The only fossil species of the Cladocopa recorded from the North American continent is *Polycope sublenticularis* Jones, collected from the Lower Silurian of Anticosti Island, Quebec. This species was transferred to the genus *Schmidtella* of the family Leperditellidae by Bassler (1915).
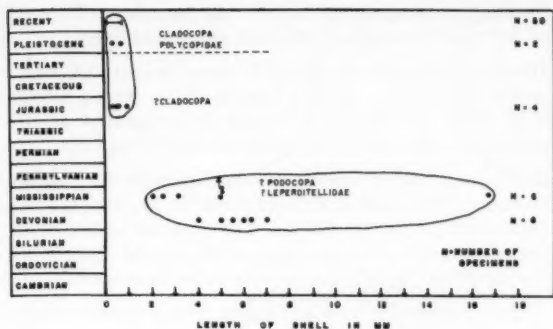
TEXT-FIGURE 2

SHELL LENGTH IN FOSSIL AND RECENT CLADOCOPA

ECOLOGY OF THE CLADOCOPA

Behavior

Cladocopids are rapid swimmers but evidently remain close to the bottom, and may be considered benthonic. However, on at least one occasion, *Polycope orbicularis* has been collected with plankton (Ostenfeld and Wesenberg-Lund, 1909). During swimming, the maxillae and the setae of the first and second antennae project from the shell anteriorly and move rapidly in a vertical plane. When the animal is disturbed, the appendages are withdrawn, and the shell is closed tightly (Sars, 1922).

Temperature

Cladocopids have been collected from near Antarctica, in water at 1.8° C. (G. W. Müller, 1908), as well as from the Bahamas, in water at 29.2° C. The group as a whole is thus markedly eurythermal. The group reaches its greatest abundance and diversity, however, in cold water (4° to 14° C.). Two additional factors suggest that the Cladocopa are essentially a cold-water group: 1) *Polycope orbicularis* has been found in glacial beds at many localities in Scotland; 2) four specimens of *Polycope orbicularis* obtained at a point 0.5 meter below the top of a sediment core collected from the mid-Atlantic ridge at a depth of 1280 meters were associated not only with cold-water ostracodes (Tressler, 1942, p. 97), but also with species of foraminifera which indicate that the water at the time when the *Polycope* lived was as cold as or colder than present-day temperatures (Cushman and Henbest, 1942, p. 41).

Salinity

Cladocopa have been reported from waters having a salinity as low as 30 parts per thousand (Elofson, 1941, p. 245). One of the Bahamian specimens here described was collected in water having a salinity of 42 parts per thousand. It seems reasonably safe to conclude, on the basis of known distribution, that Cladocopa are usually restricted to normal marine salinities — 30 to 40 or 45 parts per thousand — as delineated by Dahl (1956).

Depth

The deepest reported occurrences of cladocopids are 2600 meters for *Polycope trigonalis* Chapman, obtained from a locality near Tasmania (Chapman, 1919), and 1280 meters for *Polycope orbicularis* G. O. Sars, collected from the top of the "Faraday Hills," in the mid-Atlantic ridge (Tressler, 1942). Cladocopids are most commonly found, however, in water shallower than 500 meters, and the Bahamian specimens were collected in water only 1 to 3 meters deep. Tressler (1954) reported shells of *Polycope orbicularis* recovered from bottom samples taken at depths between 128 and 1867 meters in the Gulf of Mexico.

Bottom-type

Cladocopids have been collected from sand, sandy mud, mixed sand and shells, oyster beds, shell beds, shell debris, oyster debris, calcareous algae, loose mud, coarse sand, oyster detritus, and sand with a thin mud cover. According to Elofson (1941, p. 246), the most widespread species, *Polycope orbicularis*, is not found on clean sand bottoms. As other species of *Polycope* are present there, however, a bottom preference may exist on the species level.

PALEOECOLOGICAL VALUE OF THE CLADOCOPA

The shells of cladocopids are not strongly calcified, and because of this factor they are not readily preserved. The paleoecological value of the Cladocopa is therefore limited. Fossils of this group may indicate water of normal salinity (30 to 40 or 45 parts per thousand) at the time of deposition. The occurrence of a diverse or abundant fossil cladocopid fauna suggests cold water (4° to 14° C.), and generally suggests depths shallower than 500 meters.

EVOLUTIONARY ASPECTS OF THE PRESENT STUDY

An anterior sinus often occurs in the shells of the Myodocopa and Cladocopa, suborders whose members are usually excellent swimmers. Conversely, such a sinus is absent from the Podocopa and Platycopa, suborders whose members are mostly non-swimmers. It may therefore be assumed that an indentation (sinus) on the anterior portion of the shell is an adaptation permitting more efficient swimming, the sinus probably permitting greater freedom of the swimming appendages. The anterior

concavity that is characteristic of many Recent forms is absent in Jurassic Cladocopa; this suggests that the concavity may have been a late acquisition. If so, the development of this feature may account for the explosive increase in the number of species in Recent times. About forty-one species are known in existing seas, as compared with only one in the Pleistocene and two in the Jurassic. The development of a sinus may also have contributed to the spread of this group away from Europe, which seems to have been the principal dispersal center in the past, as well as at present.

It is also possible that the Jurassic forms are not Cladocopa, and that the Cladocopa in their present form originated in the Pleistocene. Ostracodes definitely assignable to the Cladocopa have been found only in the Pleistocene and Recent. This hypothesis would account for the apparent absence of Cladocopa in the Cretaceous, from which only one questionable form has been recorded, and in the Tertiary. Cladocopa were probably either very rare or non-existent during the Paleozoic, or possessed shells that were less readily preservable than the shells of more recent forms.

SYSTEMATICS

Order OSTRACODA Latreille

Suborder CLADOCOPA G. O. Sars

Family POLYCOPIDAE G. O. Sars, 1866

Genus POLYCOPE G. O. Sars, 1866

Polycope bahamaensis Kornicker, new species
Text-figure 3A–K

Description: Female: Shell elliptical in lateral view, but ventral edge with less curvature than dorsal edge. Greatest height a little behind the middle. Anterior distinctly bowed in middle, with a short, downward-pointing spine in center of indentation. Right valve with two small projections on posterodorsal edge; these are not present on left valve. Anteroventral edge of shell bears many small spinules, whose tips do not extend past shell margin. Shell thin, pellucid; surface smooth and without ornamentation. Anterior antennae with four joints; ultimate joint bears three long and two short setae; second joint provided with one seta in the middle of the upper edge. Exopodite of second antennae eight-jointed; endopodite three-jointed. Distal corners of caudal lamellae project downward; unfortunately, the remainder of this appendage was lost in dissection.

Male: Shell similar to female except small spine not observed above bowed anterior edge of right valve. First antennae with only four setae on ultimate joint, three long and one short, otherwise same as female. Right caudal lamella armed with seven claws that gradually diminish in length proximally. Only two claws observed on left caudal lamella of the only male examined.

Dimensions: Female: Length 0.31 mm.; height 0.26 mm.; width 0.14 mm. Male: Length 0.30 mm.; height 0.24 mm. The female specimen is designated as the holotype: Columbia University no. 28,627 (shell).

Discussion: Polycope bahamaensis closely resembles *Polycope frequens* G. W. Müller, *Polycope dispar* G. W. Müller, and *Polycope fragilis* G. W. Müller. The presence of two small projections on the posteroventral edge of the right valve distinguishes *Polycope bahamaensis* from these species.

Remarks: The only two specimens of this species which have been collected were recovered from sand which had been dry for six months. Because of this factor, the appendages were stiff and the dissection not very satisfactory.

Sample location: The Bimini Islands are situated in the northeastern part of the Great Bahama Bank and are approximately fifty miles due east of Miami, Florida. The male specimen was collected in North Sound, a small body of water formed by the junction of North and East Bimini which has restricted connection with the ocean. The female specimen was collected at a locality a few hundred yards east of South Bimini.

Ecology: The male was collected in water 2 to 3 meters deep, with a salinity of 37 parts per thousand and a temperature of 29.2^0 C. The substrate consists of rock covered by 2 feet of calcareous sand supporting patchy growths of *Thalassia* grass and the alga *Laurencia*. The female was collected in water 1 meter deep, with a salinity of 42 parts per thousand and a temperature of $29-30^0$ C. The bottom consists of calcareous sand supporting sparse *Thalassia*. Current velocities are low at both localities. The area from which the male was obtained supports a diverse and abundant ostracode community, whereas that from which the female was collected contains few ostracodes.

Polycope bahamaensis Kornicker, n. sp. A–H, female (holotype): A, outline of left valve, interior, × 120; B, right valve, interior, × 120; C, maxilla, × 576; D, first antenna, × 576; E, right valve, exterior, × 120; F, posteroventral edge of right valve, exterior, × 576; G, dorsal view of carapace, × 120; H, anterior view of carapace, × 120 (spines not shown); I–K, male: I, right caudal lamella, × 576; J, left caudal lamella, × 576; K, second antenna, × 576.

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Comments on "A simplified method of grinding foraminifera"

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The following comments may be of interest to those who read F. P. C. M. van Morkhoven's article (1958) entitled, "A simplified method of grinding foraminifera." Dr. Jan Hofker (1951), in his paper on "The toothplate-foraminifera," referred to a method of making thin sections which he called "the transparent slide method." This method has been used for some time past by a number of biologists and micropaleontologists, including the writer. The method has been found to be inexpensive and extremely useful in the preparation of sections of certain smaller and larger foraminifera and other microfossils. The writer has found that two slight modifications of the method add to the ease of operation.

The first modification is related to the fact that the ground-glass slide is quite difficult to hold while grinding is in progress. Much more satisfactory manipulation is achieved by mounting the slide in a suitable holder, fitted with a short handle. The holder used by the writer consists of a framework of thin springy steel into which the slide clips. The sides of the steel framework form an L-shaped section, one limb of which borders the upper surface of the slide, while the other limb grips the side of the slide but does not extend beyond its lower ground-glass surface. The frame consequently does not hinder the process of grinding.

The second modification concerns the fact that the stage and frame of the microscope interfere with tilting movements of the grinding slide, particularly when the operator is exposing surfaces that are convex upward. This difficulty can be overcome by mounting the specimen on a small-diameter platform that is raised above the microscope stage. This adjustment permits much greater freedom of movement. The writer has also used microdrilling tools made of stainless-steel wire, mounted in a precision chuck with a flexible variable-speed drive, to remove portions of the wall of certain larger foraminifera.

It is obvious that no single method of exposing the internal and wall structures of microfossils is necessarily the most effective in all cases. Micropaleontologists now have available such techniques as conventional or serial sectioning, acid stripping, fluorite replacement, oil immersion, and microradiography, to mention a few. Each situation has its own requirements, determined by the type of microfossil and its preservation. Whatever the techniques involved, it is clearly most desirable that workers in taxonomic micropaleontology should devote their efforts and resources toward the goal of providing first-class, accurate verbal and pictorial descriptions of the internal characteristics of those forms whose classification depends upon such characters.

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ABSTRACT: *Modern planktonic foraminiferal assemblages from quantitative plankton samples collected in the western North Atlantic reflect broad ecologic zones. The relative abundance of eight species increases southward to the Sargasso Sea, whereas that of five other species increases northward to the colder slope waters. The greatest absolute abundance of planktonic foraminifera is in the Gulf Stream system, where strong temperature and salinity gradients exist.*

Ecology of Recent planktonic foraminifera:

Part I — Areal distribution in the western North Atlantic

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INTRODUCTION

The planktonic foraminifera constitute a group of free-floating marine protozoans living in ocean waters from the surface to an undetermined depth. They possess calcareous tests which eventually settle to the ocean floor. Their remains are so ubiquitous and abundant in certain regions that they form a deposit commonly distinguished as "globigerina ooze." Correns (1939, p. 375) states that a typical globigerina ooze contains about 6000 specimens of planktonic foraminifera (larger than 200 microns in diameter) per gram of sediment. Their areal distribution is estimated by Sverdrup, Johnson and Fleming (1942) as covering the bottom of 36 per cent of the Pacific Ocean, 54 per cent of the Indian Ocean, and 67 per cent of the Atlantic Ocean — a total area of 126 million square kilometers. Globigerina oozes first became abundant in the Cretaceous. It is therefore apparent that with such wide and abundant distribution in space and time, the planktonic foraminifera are a highly significant group of organisms with which the paleontologist can interpret geologic conditions of the past.

Our knowledge of the present distribution of planktonic foraminifera has been pieced together from the researches of many investigators. Beginning with d'Orbigny's work in 1826, the early studies were necessarily taxonomic in nature and were based primarily on near-shore or exposed marine sediments and on occasional deep-sea samples. With the first world-wide oceanographic expedition of the *Challenger*, from 1872 to 1876, systematic investigations were begun on deep-sea sediments and their organic content. This regional survey (H. B. Brady, 1884) established the approximate geographic distribution of more than twenty species of planktonic

foraminifera. At the outset of the *Challenger* expedition, the planktonic habitat was still in dispute among naturalists, but Murray (1897) showed that living foraminifera were caught in surface net hauls taken during the expedition. Therefore, these forms were clearly of planktonic habit. In addition, he recognized temperature control in the distribution of tropical, temperate, and arctic-antarctic assemblages.

Subsequent oceanographic research confirmed these findings and showed that planktonic foraminifera might be used to interpret climatic changes in the past. Phillippi (1910) interpreted the globigerina oozes overlying red clays in the Indian Ocean as post-glacial deposits. Schott (1935), working in the Equatorial Atlantic, observed successive changes in the species composition of planktonic foraminiferal assemblages in the stratigraphic sequence of bottom cores, and attributed these changes to climatic variations. On this basis, he identified several glacial and interglacial stages of the Pleistocene. Many of these findings have since been amply confirmed by students of Pleistocene marine sediments, e.g., Stubbings (1939), Cushman and Henbest (1940), Phleger (1939, 1942, 1951), Phleger and Hamilton (1946), Phleger, Parker and Peirson (1953), Wiseman (1954), Wiseman and Ovey (1950), Ericson (1953), Ericson, Wollin and Wollin (1954), Ericson and Wollin (1956*a, b*), Ericson, Broecker, Kulp and Wollin (1956), and Emiliani (1955*a, b*; 1957).

The ultimate key to understanding the paleoecology of planktonic foraminifera obviously lies in the study of the ecologic conditions under which they live and in the comparison of their horizontal distribution in oceanic waters with that of empty tests on the ocean

| Plankton sample number	Date	Time	Total time of tow (min.)	Location		Depth of tow (m.)	Volume of water filtered (m³.)	Actual total plankton sample displacement volume (ml.)	Displacement volume (ml./1000m³.)
				Latitude N.	Longitude W.				
12	8/7/55	1613	23	34° 10'	60° 14'	0–270	230	8	34.8
13	8/8/55	0649	21	35° 14'	59° 30'	0–210	190	10	52.7
14	8/8/55	1822	31	35° 21'	58° 25'	0–320	245	12	49.0
15	8/9/55	1638	29	35° 07'	57° 34'	0–210	268	10	37.4
16·	8/9/55	1707	14	35° 11'	57° 36'	0–240	125	6	48.0
18	8/10/55	1345	12	35° 20'	57° 35'	0–345	90	2	22.2
19	8/11/55	1447	31	36° 32'	56° 46'	0–330	260	16	61.6
20	8/12/55	0635	31	37° 56'	59° 05'	0–210	270	12	44.5
21	8/12/55	1940	24	38° 12'	61° 10'	0–320	182	11	60.5
24	8/13/55	1841	27	38° 37'	63° 10'	0–345	205	10	48.7
25	8/14/55	0927	31	39° 56'	64° 28'	0–325	245	9	36.8
26	8/14/55	1754	25	40° 56'	62° 55'	0–240	220	18	81.9
27	8/15/55	0855	28	42° 53'	62° 07'	0–300	240	12	50.0
28	8/15/55	1740	26	42° 57'	61° 49'	0–225	234	4	17.1
29	8/16/55	0823	32	43° 48'	61° 10'	0–240	277	3	10.8
30	8/16/55	1745	30	43° 18'	58° 35'	0–235	270	4	14.8
31	8/17/55	1751	32	42° 40'	60° 00'	0–300	280	3	10.7
32	8/18/55	0854	30	42° 21'	57° 07'	0–225	275	12	43.7
33	8/18/55	1749	23	41° 55'	55° 25'	0–240	208	18	86.8
34	8/19/55	0848	31	41° 15'	52° 42'	0–300	254	10	39.4
35	8/19/55	1752	23	40° 52'	51° 07'	0–230	205	5	24.4
36	8/20/55	0836	30	40° 17'	48° 54'	0–355	220	6	27.3
37	8/20/55	1749	32	39° 06'	48° 38'	0–220	294	17	57.9
38	8/22/55	0841	33	34° 45'	50° 15'	0–270	270	10	37.1
39	8/22/55	1740	31	34° 18'	51° 23'	0–240	270	10	37.1
42	8/24/55	0835	29	32° 20'	61° 30'	0–340	253	1	39.5
44	8/25/55	0845	38	32° 30'	64° 30'	0–315	312	6	19.4
46	8/26/55	0200	49	32° 30'	64° 30'	0–220	403	12	29.8
47	8/26/55	0250	85	32° 30'	64° 30'	0–450	670	8	11.9

floor. Although the geographic distribution of plank-tonic foraminiferal species is known in a general way, there is a need for quantitative documentation. Additional quantitative studies from surface sedi-ments, similar to those of Schott (1935) in the Equatorial Atlantic, of Phleger, Parker and Peirson (1953) in the North Atlantic, and of Parker (1956) in the Mediterranean, are required in order to determine precisely the distribution of each popu-lation.

It is possible to determine the actual horizontal and vertical distribution and concentration of plank-tonic foraminifera in the sea. Thus far, however, few observations have been made on living plank-tonic forms. Rhumbler (1900, 1911) made some pertinent studies of the anatomy of the protoplasm of these animals, their food requirements, and their

concentrations in the North Atlantic. Quantitative studies of the regional distribution of the living planktonic foraminifera were also made by Lohmann (1920) in the North and South Atlantic, by Schott (1935) in the Equatorial Atlantic, by Phleger (1945, 1951) in the North Atlantic and northwest Gulf of Mexico, and by Bradshaw (MS.) in the North and Equatorial Pacific.

As the collection of plankton samples at the Lamont Geological Observatory grows, it becomes desirable to publish the results in successive papers. With continued introduction and improvement of sam-pling techniques, the samples of successive cruises are not of the same significance in quantitative analyses. Furthermore, within a cruise of only a few weeks' duration, the long-term factor can be neglected; however, this factor may be of considerable im-
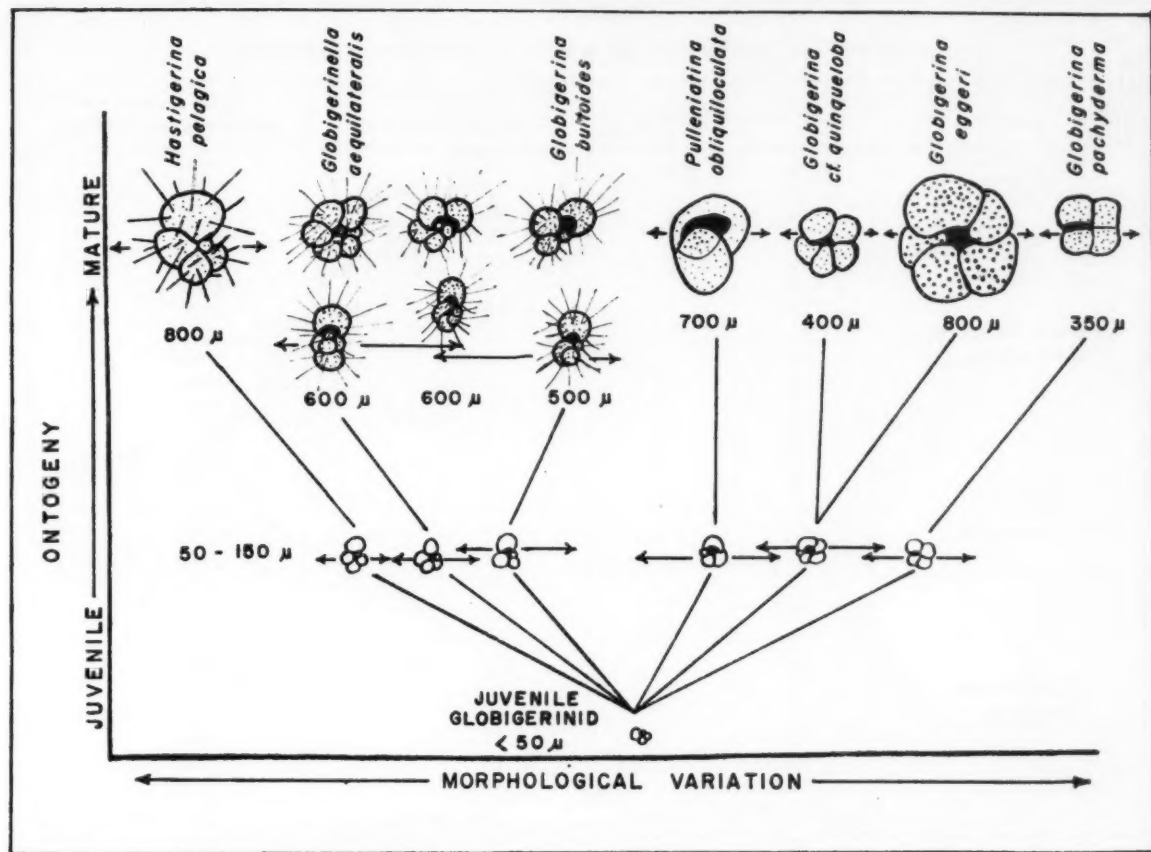
TEXT-FIGURE 1

Schematic representation of juvenile similarity and morphological intergradation among some Globigerinidae. Overlapping arrows indicate observed intergradation, the degree of which has not been determined. Non-overlapping arrows indicate morphologically distinct forms. Lengths of arrows have no quantitative significance.

portance when samples taken at different seasons are compared. Because of the broad scope of the problem under study, ecological observations cannot be evaluated with confidence until detailed horizontal and vertical studies have been undertaken over a period of several years. Thus, this and future publications on the ecology of planktonic foraminifera should be considered as limited contributions to a complex subject.

The plankton collection discussed here was obtained on the seventh cruise of the research vessel *Vema* of the Lamont Geological Observatory. The author is indebted to R. J. Menzies and R. Bieri for collecting the samples and making them available for this study at the Lamont Geological Observatory. Critical reading of the manuscript and helpful communications by J. S. Bradshaw, D. B. Ericson, F. C. Fug-

METHODS OF STUDY

Plankton studies have been handicapped by a variety of problems, foremost of which are the lack

TABLE 2

QUALITATIVE AND QUANTITATIVE ABUNDANCE OF PLANKTONIC FORAMINIFERA

	Station number	Number of species present	Total number of specimens per 1000 m³.
	12	11	1670
	13	12	1560
	14	13	3250
	15	12	1840
	16	12	5400
	18	12	4580
	19	11	3100
CENTRAL ATLANTIC	20	11	1840
WATER-MASS	21	14	1010
	24	12	6180
	38	9	1510
	40	14	5810
	42	12	430
	44	8	320
	46	11	710
	47	11	520
	16 (Total number)	11.6 (Mean)	2483 (Mean)
	25	14	7440
	26	13	2680
	29	15	4660
	32	15	12400
GULF STREAM	33	15	9620
SYSTEM	34	14	2760
	35	13	3440
	36	16	4930
	37	15	7700
	9 (Total number)	14.4 (Mean)	6181 (Mean)
	27	13	2110
SLOPE WATER	28	8	106
	30	13	230
	31	10	720
	4 (Total number)	11 (Mean)	791 (Mean)

of standardization of instruments and of methods of collection, and the great expense involved in detailed bathymetric and areal sampling of plankton. The sampling of plankton in the past has been carried out in a great many different ways depending upon the interests and purposes of various investigators and the available time. Consequently, the specialist interested in a particular taxonomic group must try to determine the degree of quantitative control or comparability of the resulting data, which depends upon the mesh size of the net, the diameter of the net opening, the type of net haul (vertical; oblique; opening-and-closing; surface), the depth-range sampled, the volume of water filtered, and the reliability of the two latter values attained. It is also necessary to record the laboratory procedures used in obtaining the given results.

In the past, plankton tows were taken with nets of either too fine a mesh (64-micron diameter or less for phytoplankton), or too coarse a mesh (500-micron diameter for the larger plankton of fisheries biologists) to be satisfactory for collecting planktonic foraminifera. The fine-meshed nets filtered too little water, whereas the latter were so coarse that most planktonic foraminifera passed through the net.

Plankton tows were taken with the express purpose of obtaining foraminifera by Schott (1935) and by Phleger (1945, 1951). The former used a 70-micron mesh net, but did not obtain a quantitative measure of the foraminiferal concentrations in the equatorial waters. Phleger (1951), in his studies in the Gulf of Mexico, used the Clarke-Bumpus plankton sampler
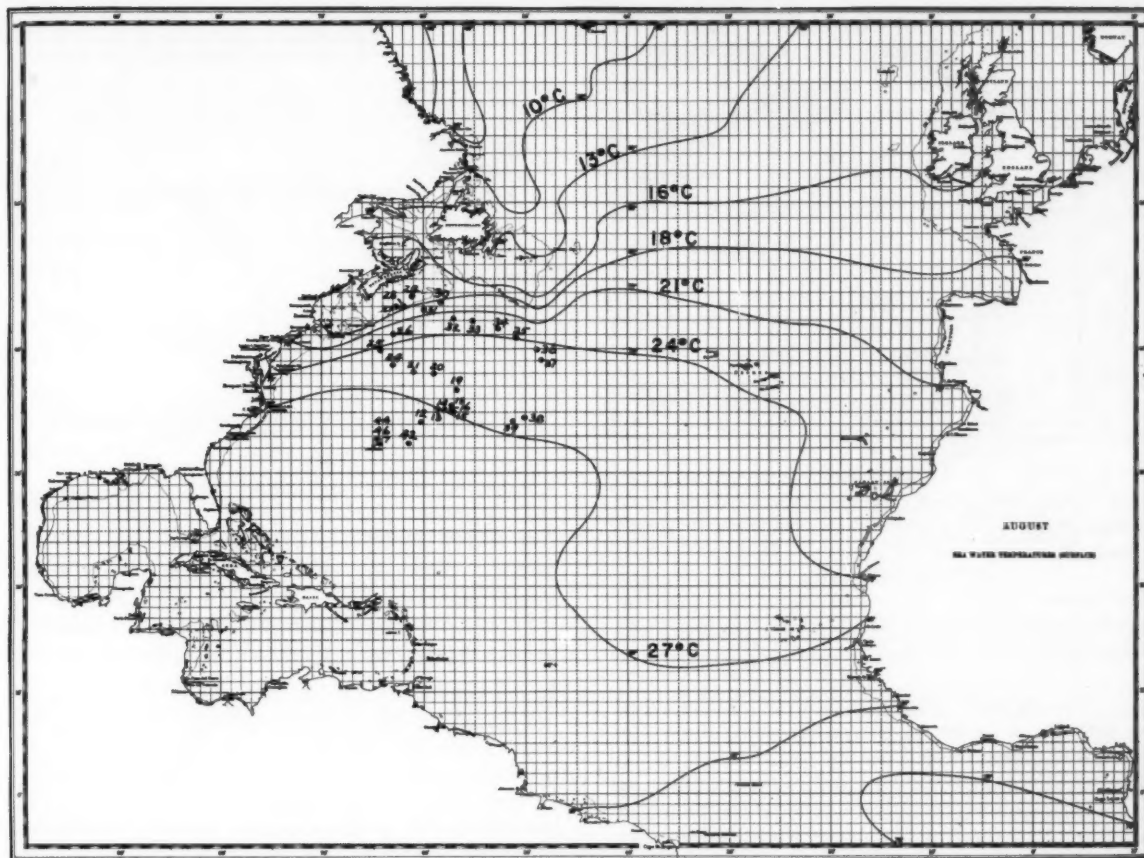
TEXT-FIGURE 2

Locations of plankton stations with surface-water isotherms for August (H. O. Misc. no. 10,555, 1943).

with a 70-micron mesh-size net; samplers of this type can be used to tow through successive depth levels by means of an opening-and-closing device, and the volume of water strained is measured by a flow meter. A disadvantage of this sampler is that the volume of water filtered is very small, and consequently the instrument must be towed for a longer time through greater distances.

The twenty-nine quantitative plankton samples used in this study were taken at fairly regular intervals in a broad area of the western North Atlantic between Bermuda and Nova Scotia. They were collected on board the R/V *Vema* of the Lamont Geological Observatory, between August 7 and 26, 1955. The locations of the stations and other pertinent data are shown in Table 1 and text-figure 9.

The oblique plankton tows were taken with a 200-micron mesh (no. 8, or 86 meshes per inch) bolting silk net having a one-half by one-half meter

face opening. This type of net is believed suitable for studying the horizontal distribution of the planktonic foraminifera. First, it retains foraminifera in large numbers and large enough to be identifiable. Second, it samples a large section of the water column, and consequently it filters a large amount of water, so that the rarer species are not neglected. Interpretation of tows of this sort assumes that (1) the concentration of planktonic foraminifera is roughly constant in the upper 300 meters of water, (2) there is no appreciable vertical migration during corresponding daylight hours (in which most of the plankton samples were taken), and (3) there is no significant species stratification with depth.

A current meter was not available during the *Vema* cruise on which these samples were taken. The volume of water filtered was estimated by multiplying the area of the net opening (0.25 m².) by the distance which the net traveled (twice the length of wire paid
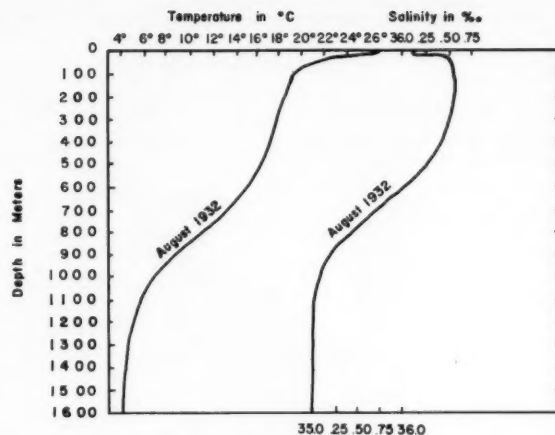
81
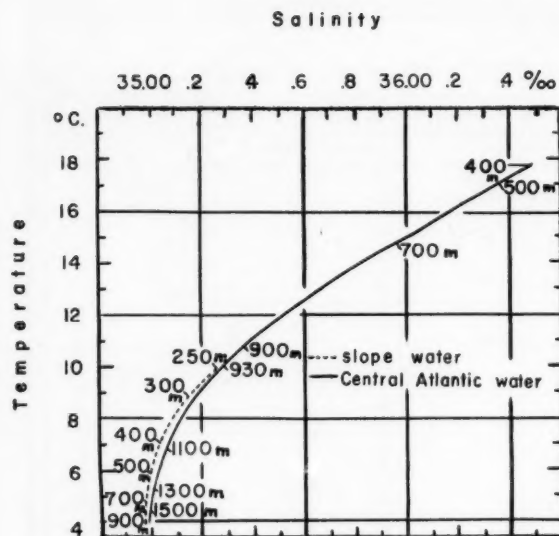
Salinity

TEXT-FIGURE 3

Comparison between the mean temperature–salinity correlations of the slope water and of the Sargasso water (after Iselin, 1936, text-fig. 23).

TEXT-FIGURE 4

Average temperature and salinity with depth in August, 1932, in the Sargasso Sea (after Iselin, 1936, text-fig. 19).

out). This estimate gives maximal values that may be high by a factor of two, depending upon the amount of water filtered during the lowering of the net and the changes in wire angle. It was assumed that with a wire angle larger than 20° there is enough strain to allow filtering through the net both during lowering and raising. The problem of clogging probably did not enter here because of the relatively coarse mesh size of the net and the low standing crop of plankton in the area surveyed. The volume of water filtered for the twenty-nine samples ranged from 90 to 670 cubic meters.

The depth of each plankton tow was obtained trigonometrically by assuming a straight wire from the ship to the net and by closely observing any changes in wire angle at the maximum depth. The oblique tows did not favor any particular depth, since they were lowered and raised at a uniform rate (about 20 m./min.). The wire angle was kept as constant as possible (about 40°), but varied with the current and the speed of the ship. Although this method was not precise, the error involved in obtaining the maximum depth probably was not greater than 10 per cent. The maximum depths of the tows ranged from 210 to 355 meters.

All plankton samples were carefully washed from the nets to avoid contaminating the subsequent series of tows. The samples were preserved in 5 per cent formalin buffered by hexamethylenetetramine.

Clearly, there are many problems involved in quantitative sampling, but, despite the limitations of the method, samples taken uniformly are comparable among themselves.

In the laboratory, a procedure was adopted to speed the faunal analyses while retaining the true species composition. Certain planktonic foraminiferal species often greatly exceeded other species in number. In such cases it was impracticable to count each individual of these common species. Therefore, whenever a species was estimated to exceed 100 specimens, only one-tenth of these individuals were counted, although a total count was made of species having less than 100 individuals.

To assure a random estimate count of the more abundant species, a lucite tray marked off by a 100-square grid system was used. As the plankton poured into the tray may concentrate in localized areas, those individuals were counted which occupied the ten squares in the diagonal of the tray. A hand vary-tally for ten species-groups was employed for tabulation during microscopic examination. A large fraction of the planktonic foraminifera was removed with a finely tapering pipette from the plankton samples and stored in buffered formalin in vials for future reference and comparison.

The abundance of each species is expressed as (1) number of individuals per 1000 m³. of water, i.e., a measure of the standing crop, and (2) percentage of the total foraminifera in each sample. The latter measure is especially useful in comparing the species composition of the surface sediments with that of the overlying water column.
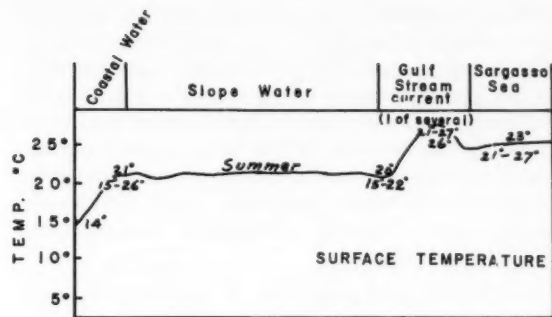
TEXT-FIGURE 5

Mean surface temperature of coastal water, slope water, Gulf Stream current, and the Sargasso Sea (modified from Strack, 1953).

DISCUSSION OF TAXONOMY

In this study, the taxonomy of Phleger, Parker and Peirson (1953) has been followed. The following nineteen species were recognized in the plankton samples from the western North Atlantic:

Globorotalia menardii (d'Orbigny) (pl. 1, figs. 1–3)
Globorotalia hirsuta (d'Orbigny) (pl. 1, figs. 4, 8)
Globorotalia punctulata (d'Orbigny) (pl. 1, figs. 9–11)
Globorotalia truncatulinoides (d'Orbigny) (pl. 1, figs. 5–7)
Globigerinita glutinata (Egger) (pl. 1, figs. 25–26)
Globigerina inflata d'Orbigny (pl. 1, figs. 12–14)
Globigerina bulloides d'Orbigny (pl. 1, figs. 15–17)
Globigerina eggeri Rhumbler (pl. 2, figs. 1–3)
Globigerina pachyderma (Ehrenberg) (pl. 1, figs. 23–24)
Globigerina cf. *quinqueloba* Natland (pl. 1, figs. 21–22)
Globigerinoides ruber (d'Orbigny) (pl. 2, figs. 16–17)
Globigerinoides sacculifer (H. B. Brady) (pl. 2, figs. 13–15)
Globigerinoides conglobatus (H. B. Brady) (pl. 2, figs. 7–12)
Orbulina universa d'Orbigny (pl. 2, fig. 18)
Pulleniatina obliquiloculata (Parker and Jones) (pl. 2, figs. 4–6)
Candeina nitida d'Orbigny (pl. 2, figs. 19–20)
Hastigerina pelagica (d'Orbigny) (pl. 2, figs. 21–22)
Globigerinella aequilateralis (H. B. Brady) (pl. 1, figs. 19–20, 27)
Hastigerinella rhumbleri Galloway (pl. 2, fig. 23)

Two varieties of *Globigerinoides ruber* are recognized on the basis of the color of the test. Although color gradations between pink tests and white tests can be found, the two varieties were established on the basis of their predominant color. The color variations may not have any taxonomic significance. Here the objective was to determine whether or not the test color had any ecological importance.

The taxonomy of the Recent planktonic foraminifera is in a state of flux due to the large number of
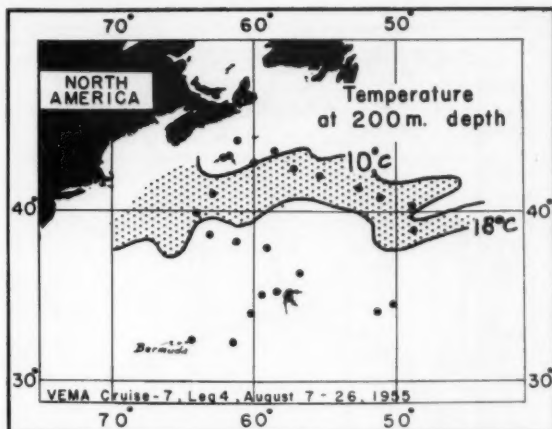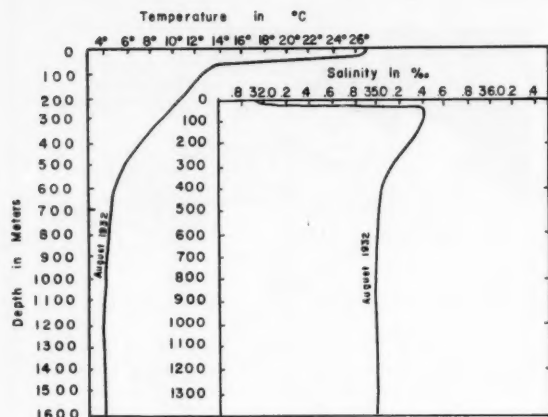

TEXT-FIGURE 6

The Gulf Stream system (stippled band), bounded by the 10° C. and 18° C. isotherms at a depth of 200 meters. Slope water is to the north, Sargasso Sea to the south. Temperature data from Fuglister (1954).

specific names that have arisen from limited and isolated studies. The "Catalogue of Foraminifera" (Ellis and Messina, 1940) lists over sixty species of Recent planktonic foraminifera, named by more than fifteen different authors. H. B. Brady (1884), Rhumbler (1911), Schott (1935), Phleger, Parker and Peirson (1953), and Ericson and others (1953, 1954, 1956), in their works of regional scope, recognized only a limited number of species, and, more significantly, they recognized approximately the same twenty-odd species.

Certain species are taxonomically unstable because of the following factors: (1) There is an overlapping range of morphologic variation in adult individuals of some closely related species (infra- or inter-specific variation), which results in intergradation between forms that have been established as separate species; (2) there is morphologic similarity among the juveniles of many different species; (3) there is lack of agreement as to the relative significance of observable characters.

Juvenile similarity and morphologic intergradation among some members of the Globigerinidae is shown diagrammatically in text-figure 1. Here intergradation is indicated by overlapping horizontal arrows, the lengths of which have no absolute values and indicate merely that overlaps exist as determined by inspection. The similarity in appearance is especially striking among globigerinids smaller than 50 microns; hence, a great deal of ontogenetic morphologic overlap is present, so that it is almost impossible to differentiate the small

Temperature in °C

Salinity in ‰

Depth in Meters

August 1932

TEXT-FIGURE 7

Average temperature and salinity with depth in August, 1932, in the slope water off Chesapeake Bay (after Iselin, 1936, text-fig. 17).

specimens belonging to *Hastigerina pelagica, Globigerinella aequilateralis, Globigerina bulloides, Pulleniatina obliquiloculata, Globigerina eggeri*, and *Globigerina pachyderma*. There is loss of optical resolution at this small size because of the necessarily high magnification, and the certainty of the identification therefore bears a direct relation to the size of the test. Differentiating characters appear gradually in the ontogeny, but they are still difficult to detect at the 150-micron size level.

Juveniles less than 150 microns in size in the following species-groups often cannot be distinguished from each other:

1) *Globigerinella aequilateralis – Globigerina bulloides – Globigerinita glutinata – Orbulina universa* (spiral form) *– Globigerinoides conglobatus.*
2) *Pulleniatina obliquiloculata – Globigerina eggeri – Globigerina pachyderma.*
3) *Globorotalia hirsuta – Globorotalia punctulata – Globigerina inflata.*
4) *Globigerinoides ruber – Globigerinoides sacculifer – Globigerinita glutinata.*
5) *Globorotalia menardii – Globorotalia tumida.*

It must be noted that because the plankton samples in this study were taken with nets having an average mesh diameter of 200 microns, a large number of juveniles were not retained in the nets. In general, these samples contained sufficient numbers of adults so that the writer was reasonably certain of the species represented.

Morphologic intergradation between nominate species in mature tests (larger than 500 microns) is present between *Globigerina bulloides* and *Globi-*

gerinella aequilateralis (see pl. 1, fig. 18). The adults of *Globigerinella aequilateralis* may vary from perfectly planispiral to left- or right-coiling asymmetrical forms. The asymmetry may start early or late in the ontogeny, and such adults tend to grade into those of *Globigerina bulloides*. Morphologic intergradation in adult forms can also be noticed to a certain extent between *Globorotalia punctulata* and *Globorotalia hirsuta*, and between *Globorotalia menardii* and *Globorotalia tumida*.

Ontogenetic intergradation is interpreted as a natural consequence of the development and differentiation of these organisms. Intergradation between adults suggests that all are not taxonomically "good" species in the genetic sense. Subspecies may be represented in several cases, but until extensive taxonomic studies are made with the purpose of determining population structure, it seems inadvisable to suggest taxonomic changes at this time. Aside from intergrading variants, the majority of adult specimens in a sample are readily identifiable, and hence are as useful as species *per se* in showing ecologic relationships.

GENERAL PHYSICAL OCEANOGRAPHY

The area under discussion is the northwestern sector of the North Atlantic current gyral. The central water-mass (Sargasso Sea) is bounded by a clockwise current system (North Equatorial Current, Antilles Current, Florida Current, Gulf Stream currents, North Atlantic Current, Azores Current, and the Canary Current). Our interest lies in a roughly triangular area between Bermuda and the Maritime Provinces of Canada (text-fig. 9).

Iselin (1936) recognized four major water-masses in this region of the western North Atlantic: (1) The Central Atlantic water-mass (or Sargasso Sea); (2) the Gulf Stream system; (3) the slope water, roughly occupying the region of the continental slope; and (4) the coastal waters, toward shore (not considered here). Each of these water-masses has its characteristic hydrographic properties, and, consequently, significant differences in the planktonic faunas might be expected between them. This expectation is substantiated by the distributional patterns of the planktonic foraminifera to be discussed later in the present paper.

In this study, four stations (nos. 27, 28, 30, 31) are considered to lie within the slope-water area; nine stations (nos. 25, 26, 29, 32, 33, 34, 35, 36, 37) within the Gulf Stream system; and sixteen (nos. 12–24, 38, 39, 42, 44, 46, 47) within the Sargasso Sea. The average surface-water temperatures for these stations are presented in text-figure 2.
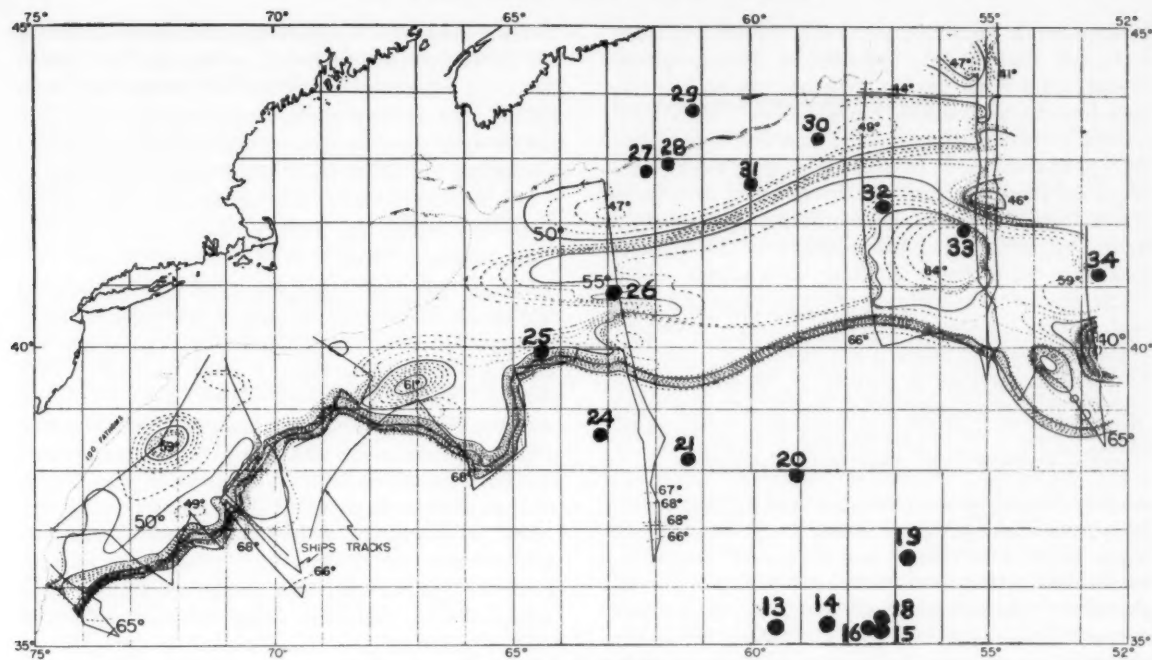
Superposition of the plankton stations on Fuglister's chart (1954, p. 222) of temperatures at a depth of 200 meters in August, 1953. The Gulf Stream system is bounded by the 10° C. and 18° C. isotherms.

Central Atlantic water-mass (Sargasso Sea)

This central water-mass is characterized by relatively warm saline waters, which show smaller seasonal temperature and salinity fluctuations than the other three water-masses. At equivalent depths, the temperature and salinity properties of the Sargasso Sea are markedly distinct from those of the slope water (text-fig. 3). The greatest temperature fluctuations occur in the upper 300 meters of water. The temperature profile (text-fig. 4) shows that summer heating produces only a shallow warm layer and that heat conduction downward takes place at a slow rate. Consequently, the greatest temperature differences between the surface and a depth of 300 meters occur in August, and the differences are least in early March. The layer above the seasonal thermocline is shallowest in the summer months and deepest in the winter months (Fuglister, 1947, text-fig. 30). The seasonal variations of the average surface temperatures range between 19° and 26° C., in March and in August, respectively. During August, surface isotherms vary from about 26° C. in the area of Bermuda to about 24° C. on the southern boundary of the Gulf Stream system; at a depth of 200 meters, the isotherms vary from about 19° C. in Bermuda to about 18° C. on the southern edge of the Gulf Stream system (Fuglister, 1947, 1954).

The average surface salinity varies from 36.25 parts per thousand in August, to 36.65 parts per thousand in April. However, at a depth of about 300 meters the salinity remains at about 36.50 parts per thousand at all seasons. During August the surface isohalines vary from 36.30 parts per thousand around Bermuda to about 36.00 parts per thousand on the southern edge of the Gulf Stream system; at a depth of about 200 meters the isohalines remain constant at 36.50 parts per thousand throughout this water-mass (Fuglister, 1947, 1954).

Gulf Stream system

Bounding the Central Atlantic water-mass on the west and north is the Gulf Stream system. The characteristics of this current system are apparently complex and not easily resolved. Sverdrup, Johnson and Fleming (1942) restrict the Gulf Stream system to an area extending from the continental slope off Cape Hatteras to the region east of the Grand Banks. Early observations noted a well-defined current within this region flowing like an "ocean-river" in a northeasterly direction. Such a concept is obtained from the average-temperature charts and from observations of water movements over long periods of time. These average conditions denote a meandering band, about 150 kilometers wide, having strong temperature and salinity gradients.

Recent work by Fuglister (1951, 1955), however, indicates that in the process of averaging the temperature data, the Gulf Stream system appears as a broader and weaker current than it actually is at any given time. He showed that four alternative interpretations are possible for the same data obtained from a survey of currents. For sections of the Gulf Stream system the isotherms can be drawn to show any of the following features: (1) A single gradient; (2) a single gradient with eddies; (3) a single gradient branching off into other currents with eddies or countercurrents between them; or (4) a complicated pattern of "turbulent" currents and countercurrents. A current of the Gulf Stream system at a particular time and place may vary considerably from the mean conditions of location, velocity, transport and water-mass characteristics.

Fuglister and Worthington (1951) also showed that in a given linear group of isotherms, it is possible to draw either anticyclonic (clockwise) eddies to the north of one of the Gulf Stream branches or cyclonic (counter-clockwise) eddies to the south of it. Such a separation of a part of the Gulf Stream system into a separate cyclonic eddy to the south of it was actually observed in detailed shipboard measurements. Similar intrusions into the slope water by eddies originating from the northern edge of the Gulf Stream system are also known to occur on the Nova Scotian Shelf (Hachey, 1939; Hachey *et al.*, 1954). The dynamic conditions of the Gulf Stream system are pointed out here so that the reader will be aware of the difficulties in correlating *average* hydrographic data with foraminiferal distributions within these highly variable waters.

An actual horizontal change in surface temperature from coastal water to Sargasso Sea is shown in text-figure 5. It should be noted that at the outer or right-hand edge of the Gulf Stream, there is a slight drop in surface temperature with respect to the warmer inner core of the Gulf Stream current. Similarly, there is a slight rise in temperature at the inner or left-hand edge of the Gulf Stream current boundary in comparison with the warm inner core. During the summer months, the horizontal surface-temperature changes from the outer to the inner boundaries of the current can vary from a minimum range of 15–21° C. to a maximum range of 22–27° C. The mean horizontal temperature change is from 20° to 26° C. These are mean temperature conditions for summer surface waters of one current of the Gulf Stream system. However, since there are multiple Gulf Stream currents and countercurrents, it is to be expected that the temperature ranges given above may be repeated several times across the path of the system.

During August a temperature change from 10° to 18° C. can still be observed at a depth of 200 meters within a horizontal distance of 150 kilometers (text-fig. 6). The average surface salinity within the Gulf Stream system varies around 36.50 parts per thousand; at a depth of 200 meters the salinity varies from 36.50 to 35.50 parts per thousand (Iselin, 1936; Fuglister, 1954).

Slope-water area

Between the Gulf Stream system and the coastal waters is a water-mass commonly designated as slope water. As such it is transitional in its temperature and salinity properties between the warmer saline Gulf Stream waters and the colder, fresher coastal waters. The slope water increases in lateral extent from a narrow strip off Cape Cod to a wide band south of Newfoundland. At given depths it has characteristic temperature and salinity properties which differentiate it from the Central Atlantic water-mass (text-fig. 3).

Iselin's (1936) temperature profile shows that large temperature differences occur in the upper 100 meters (text-fig. 7). In August the average temperature is 23° to 26° C. at the surface, 13° C. at 100 meters, 10° C. at 200 meters, and 8° C. at a depth of 300 meters. The average salinity observations for August are 33.80 parts per thousand at the surface, 35.40 parts per thousand at 100 meters, 35.30 parts per thousand at 200 meters, and 35.10 parts per thousand at 300 meters (Iselin, 1936; Fuglister, 1954).

The upper 200 meters of slope water appears to originate from the mixing of Gulf Stream waters and lower-salinity waters of the continental shelf ("coastal water"). Because of its relatively higher density, it periodically flows toward the coast underneath the less dense coastal waters. As a result of the constant shifting and meandering of the Gulf Stream system and the frequent northward incursions of severed portions of the Gulf Stream water-masses onto the continental shelf, it is possible that subtropical marine faunas may be found incorporated in the normally colder water-masses. This is an important process whereby cold- and warm-water faunal assemblages become mixed.

AREAL DISTRIBUTION OF PLANKTONIC FORAMINIFERA IN THE WESTERN NORTH ATLANTIC

In the area under discussion there is no conspicuous segregation of species into restricted horizontal zones. Most species are found throughout the region. Their concentrations vary on a statistical basis within the three water-masses. Several rare species, *Candeina nitida, Pulleniatina obliquiloculata, Globigerina*

digitata, Globigerina pachyderma, and *Globorotalia hirsuta,* are sporadically distributed and show no significant pattern of distribution.

Each species is represented by (1) the number of specimens per 1000 m³. of water filtered, and (2) the percentage of the total population of planktonic foraminifera in each sample. The former value is a measure of the standing crop, i.e, the abundance of the organisms in a given volume of water at a particular time; the latter value is a function of two reaction patterns — that of the individual species and that of the total foraminiferal assemblage. The distribution of each of the eighteen planktonic foraminiferal species is shown in text-figures 13 to 52.

Three contour intervals are superimposed over the raw data in these figures; the limits of the intervals vary from species to species. The contour boundaries were determined empirically, and vary from one map to another. They have been drawn, when possible, to emphasize relationships to the prevailing Gulf Stream current system. Plots of the northern plankton stations upon Fuglister's chart (1954, p. 222) (see text-fig. 8) of average temperatures at a depth of 200 meters, and, conversely of the 10° C. and 18° C. isotherms of Fuglister's chart on the map showing the locations of stations (text-fig. 6) reveal that stations 25, 26, 32, 33, 34, 35, 36, and 37 fall between these two isotherms. The steep temperature and salinity gradients found between these two isotherms define the main path of the Gulf Stream system. Within this zone there is a relatively large increase in the total abundance and in the number of species of planktonic foraminifera (text-fig. 12 and Table 2).

Absolute abundance of total planktonic foraminifera

The total number of planktonic foraminifera observed within the Gulf Stream system exceeds 3000 specimens per 1000 m³. of water filtered (stations 24, 25, 32, 33, 35, 36, 37, and 38; see Table 2). Highest concentrations (up to 12,400 specimens/1000 m³. water) are found at the northern edge of the Gulf Stream system (stations 25, 32 and 33). There is a rapid transition to a relatively impoverished region north of the Gulf Stream system, where the total planktonic foraminiferal population drops to less than 1000 specimens per 1000 m³. of water (stations 27, 28, and 30). Station 29 is anomalous in having a large number of specimens and a large number of species; this may be interpreted as a biological indication of an eddy intrusion of Gulf Stream waters into the relatively cold slope-water region. Physical and biological evidences of such features have been observed by Fuglister (1951), Hachey

(1939), Iselin (1936, p. 14), and Riley, Stommel and Bumpus (1949, p. 34).

Number of species of planktonic foraminifera

Table 2 indicates that the highest number of species (fifteen or more out of a total of eighteen) are present at the Gulf Stream stations (stations 29, 32, 33, 36, and 37). Fewer species are present on either side of the Gulf Stream system (stations 28, 31, and 38).

Absolute abundance of individual species

The concentration of individual foraminiferal species also shows a marked increase in the Gulf Stream system in contrast to the slope water and Sargasso Sea regions. Species that have their greatest abundance in the Gulf Stream system are *Globorotalia menardii, Globorotalia punctulata, Globigerina inflata, Globigerina pachyderma, Globigerina eggeri, Globigerinita glutinata, Globigerinoides ruber, Globigerinoides sacculifer, Globigerinoides conglobatus,* and *Globigerinella aequilateralis.* Species that are found abundantly in the slope water and in the Gulf Stream system are *Globigerina bulloides, Globigerina eggeri* and *Globigerina* cf. *quinqueloba.* Species that have their greatest concentration in the Sargasso Sea region are *Globorotalia truncatulinoides* and *Hastigerina pelagica. Orbulina universa* seems to be most abundant in the western and southwestern part of this region, and does not clearly show a maximal development eastward.

Relative abundance of individual species

The second method of presentation, i.e., the percentage of the total population of planktonic foraminifera, shows distributional patterns that are different from those derived by the first method. Whereas the greatest absolute abundance of most species is found in the Gulf Stream system, the greatest relative abundance of certain species, expressed as per cent of total population, is found in other areas. Thus, there is a roughly latitudinal segregation of what may conveniently be termed here "cold-" and "warm-tolerant" species. Toward the north, in the slope water and in the northern Gulf Stream stations, there is a percentage increase of the following cold-tolerant species: *Globigerina inflata, Globigerina bulloides, Globigerina eggeri, Globigerina pachyderma, Globigerinita glutinata,* and, to a small extent, *Globorotalia hirsuta* and *Pulleniatina obliquiloculata.*

From an analysis of percentage data it is thus possible to segregate planktonic foraminifera into warm- and cold-tolerant species according to their preference for relatively warm or cold waters in this region. These groups of species are tabulated below:

Cold-tolerant species	Warm-tolerant species
Globigerina inflata	*Hastigerina pelagica*
Globigerina eggeri	*Globigerinella aequi-*
Globigerina bulloides	*lateralis*
Globigerina pachyderma	*Globigerinoides sacculifer*
Globigerinita glutinata	*Globorotalia punctulata*
* *(Pulleniatina obliqui-*	*Globorotalia menardii*
loculata)	*Globigerinoides ruber*
* *(Globorotalia hirsuta)*	*Orbulina universa*
	* *(Candeina nitida)*
*Distribution pattern indefinite	*Globigerinoides conglobatus*

The provincial segregation of the cold-tolerant species is more marked than that of the warm-tolerant species, for each of the former species definitely decreases in percentage as well as in abundance southward, although all of the cold-tolerant species show a consistently high abundance in the northern plankton stations (stations 29–37). The percentage of warm-tolerant species increases southward, and, with the exception of *Hastigerina pelagica*, they show a secondary decrease in percentage and abundance farther south. These southern minima occur within the Sargasso Sea, which is reputed to have a relatively small standing crop and productivity of total plankton (Clarke, 1940). This factor presumably may also affect foraminiferal concentrations. Although *Orbulina universa* and *Globigerinoides ruber* are here considered to be warm-tolerant species, they are abundant throughout the region, except in the slope water. Their percentage maxima are rather peculiar in that *Orbulina universa* is most abundant in the western portion, whereas *Globigerinoides ruber* increases eastward, having a minimal region toward the west.

Relationship between total planktonic foraminifera and total plankton

A general direct correlation exists between the standing crops of the total planktonic foraminifera (text-fig. 12) and of the total plankton (text-fig. 11). These diagrams indicate that both the planktonic foraminifera and the total plankton have their peak concentrations in the Gulf Stream system, and that they diminish in quantity northward in the slope water and southward in the Bermuda region.

CONCLUSIONS

The present study is an attempt to define the broader aspects of the horizontal distribution of planktonic foraminifera and to relate this distribution to known *average* temperature and salinity conditions. The vertical distribution of these organisms remains unknown, and few hydrographic observations accompanied the present samples; the data accordingly have had to be referred to average conditions. Lack-

ing a knowledge of their vertical distribution, it is not possible to determine any vertical variations in the foraminiferal concentrations, or whether or not there is any species stratification with depth. Consequently, it is also impossible at this time to determine the *optimum* conditions and range of tolerances of the foraminiferal concentrations in relation to such ecologic factors as salinity, temperature, light or nutrients.

Nevertheless, certain general facts can be distinguished. First, there are more species represented in the Gulf Stream system than in the slope water to the north or the Sargasso Sea to the south. Second, fourteen species present in the Gulf Stream system are more abundant in these waters than in the other two water-masses. This fact seems to indicate that the greatest foraminiferal concentration in this part of the Atlantic is in the region of relatively strong currents and steep temperature and salinity gradients. Third, the percentage of the warm-tolerant species — *Globigerinoides sacculifer*, *Globigerinoides ruber*, *Globigerinoides conglobatus*, *Globigerinella aequilateralis*, *Hastigerina pelagica*, *Orbulina universa*, *Globorotalia menardii*, and *Globorotalia punctulata* — is greatest south of the Gulf Stream system. Conversely, the percentage of the cold-tolerant species — *Globigerina inflata*, *Globigerina pachyderma*, *Globigerina bulloides*, *Globigerina eggeri* and *Globigerina* cf. *quinqueloba* — is largest north of it. Fourth, station 29, which is located in the normally cold slope-water region and from which an assemblage of warm-tolerant species was obtained lends biological support to physical evidence of eddy intrusions of Gulf Stream waters into the slope water.

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EXPLANATION OF TEXT-FIGURES 9–52

TEXT-FIGURES 9–14

9, locations of oblique-plankton-tow collections in the western North Atlantic, August 7–26, 1955; 10, maximum depths of the tows (in meters); each oblique tow was taken from the maximum depth indicated to the surface; 11, total zooplankton displacement volumes in ml./1000 m³.; 12, distribution of total planktonic foraminifera expressed as number of specimens per 1000 m³. of water filtered; 13, distribution of *Globorotalia menardii* expressed as number of specimens per 1000 m³. of water filtered; 14, distribution of *Globorotalia menardii* expressed as per cent of total planktonic foraminifera.

TEXT-FIGURES 15–20

15, distribution of *Globorotalia hirsuta* expressed as number of specimens per 1000 m³. of water filtered; 16, distribution of *Globorotalia hirsuta* expressed as per cent of total planktonic foraminifera; 17, distribution of *Globorotalia punctulata* expressed as number of specimens per 1000 m³. of water filtered; 18, distribution of *Globorotalia punctulata* expressed as per cent of total planktonic foraminifera; 19, distribution of *Globorotalia truncatulinoides* expressed as number of specimens per 1000 m³. of water filtered; 20, distribution of *Globorotalia truncatulinoides* expressed as per cent of total planktonic foraminifera.

TEXT-FIGURES 21–26

21, distribution of *Globigerinita glutinata* expressed as number of specimens per 1000 m³. of water filtered; 22, distribution of *Globigerinita glutinata* expressed as per cent of total planktonic foraminifera; 23, distribution of *Globigerina inflata* expressed as number of specimens per 1000 m³. of water filtered; 24, distribution of *Globigerina inflata* expressed as per cent of total planktonic foraminifera; 25, distribution of *Globigerina bulloides* expressed as number of specimens per 1000 m³. of water filtered; 26, distribution of *Globigerina bulloides* expressed as per cent of total planktonic foraminifera.

TEXT-FIGURES 27–32

27, distribution of *Globigerina eggeri* expressed as number of specimens per 1000 m³. of water filtered; 28, distribution of *Globigerina eggeri* expressed as per cent of total planktonic foraminifera; 29, distribution of *Globigerina pachyderma* expressed as number of specimens per 1000 m³. of water filtered; 30, distribution of *Globigerina pachyderma* expressed as per cent of total planktonic foraminifera; 31, distribution of *Globigerina* cf. *quinqueloba* expressed as number of specimens per 1000 m³. of water filtered; 32, distribution of *Globigerina* cf. *quinqueloba* expressed as per cent of total planktonic foraminifera.

TEXT-FIGURES 33–38

33, distribution of *Globigerinoides ruber* (pink) expressed as number of specimens per 1000 m³. of water filtered; 34, distribution of *Globigerinoides ruber* (pink) expressed as per cent of total planktonic foraminifera; 35, distribution of *Globigerinoides ruber* (white) expressed as number of specimens per 1000 m³. of water filtered; 36, distribution of *Globigerinoides ruber* (white) expressed as per cent of total planktonic foraminifera; 37, distribution of *Globigerinoides ruber* (pink and white) expressed as number of specimens per 1000 m³. of water filtered; 38, distribution of *Globigerinoides ruber* (pink and white) expressed as per cent of total planktonic foraminifera.

TEXT-FIGURES 39–44

39, distribution of *Globigerinoides sacculifer* expressed as number of specimens per 1000 m³. of water filtered; 40, distribution of *Globigerinoides sacculifer* expressed as per cent of total planktonic foraminifera; 41, distribution of *Globigerinoides conglobatus* expressed as number of specimens per 1000 m³. of water filtered; 42, distribution of *Globigerinoides conglobatus* expressed as per cent of total planktonic foraminifera; 43, distribution of *Orbulina universa* expressed as number of specimens per 1000 m³. of water filtered; 44, distribution of *Orbulina universa* expressed as per cent of total planktonic foraminifera.

TEXT-FIGURES 45–50

45, distribution of *Pulleniatina obliquiloculata* expressed as number of specimens per 1000 m³. of water filtered; 46, distribution of *Pulleniatina obliquiloculata* expressed as per cent of total planktonic foraminifera; 47, distribution of *Candeina nitida* expressed as number of specimens per 1000 m³. of water filtered; 48, distribution of *Candeina nitida* expressed as per cent of total planktonic foraminifera; 49, distribution of *Hastigerina pelagica* expressed as number of specimens per 1000 m³. of water filtered; 50, distribution of *Hastigerina pelagica* expressed as per cent of total planktonic foraminifera.
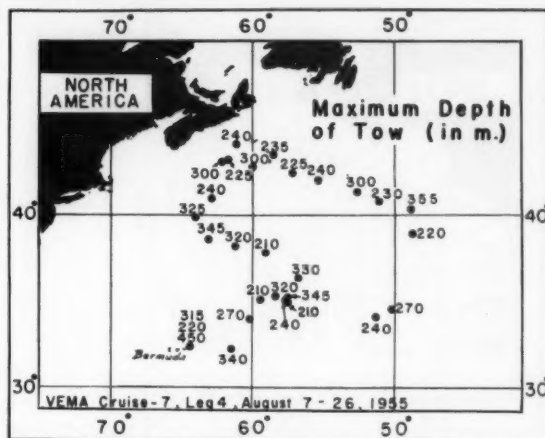
TEXT-FIGURES 51–52

51, distribution of *Globigerinella aequilateralis* expressed as number of specimens per 1000 m³. of water filtered; 52, distribution of *Globigerinella aequilateralis* expressed as per cent of total planktonic foraminifera.
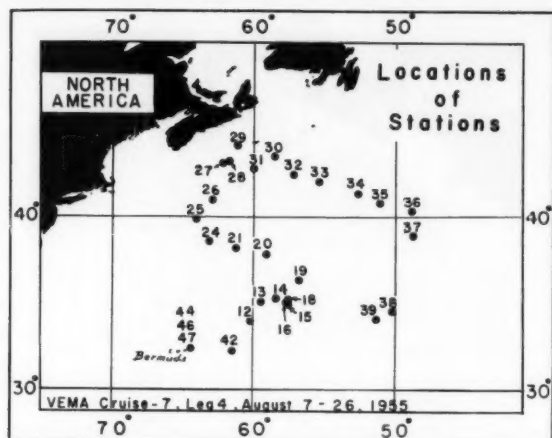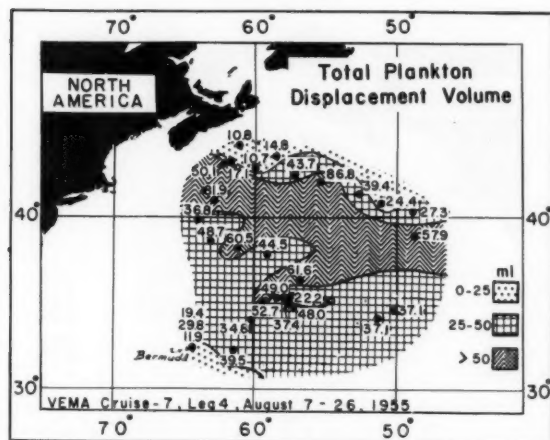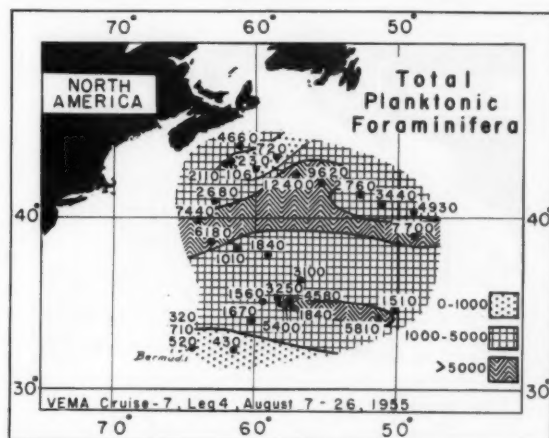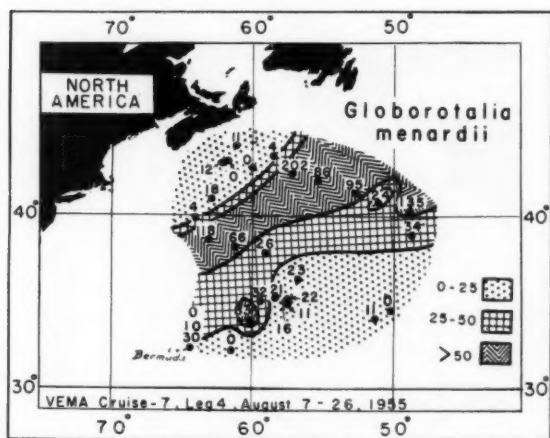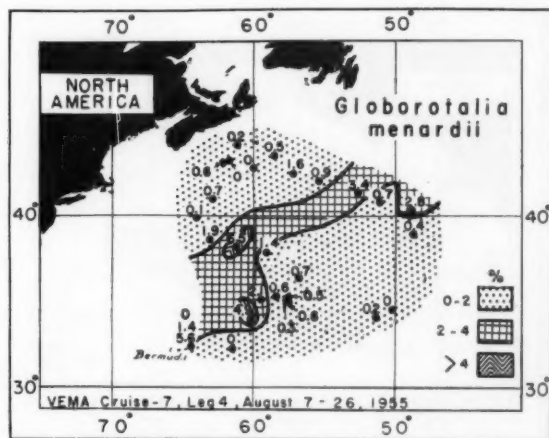
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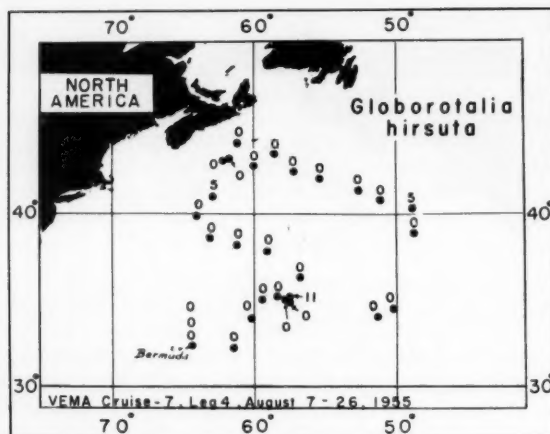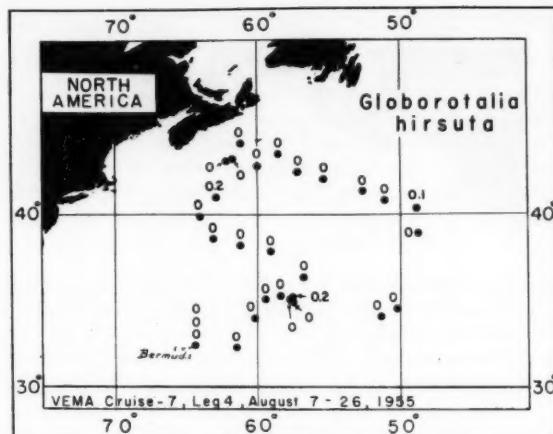

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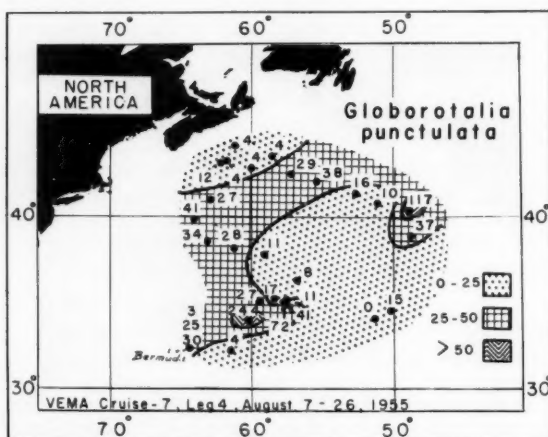TEXT-FIGURE 11

TEXT-FIGURE 12
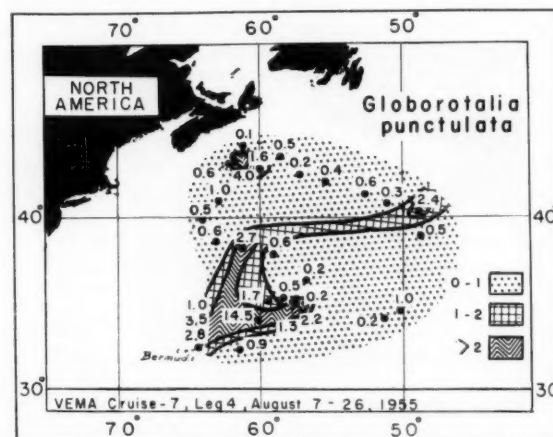

TEXT-FIGURE 13

TEXT-FIGURE 14
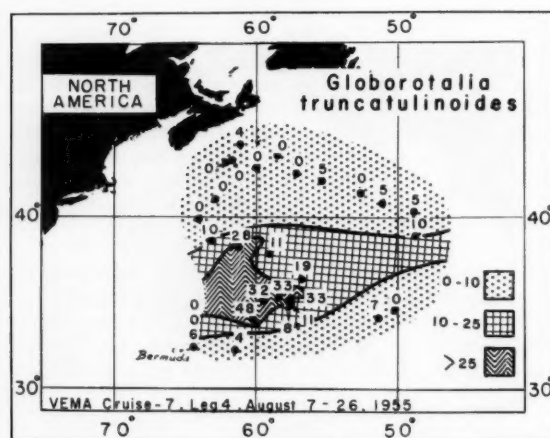
TEXT-FIGURE 15

TEXT-FIGURE 16

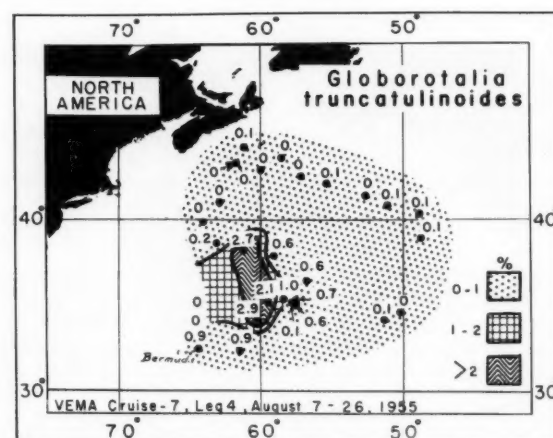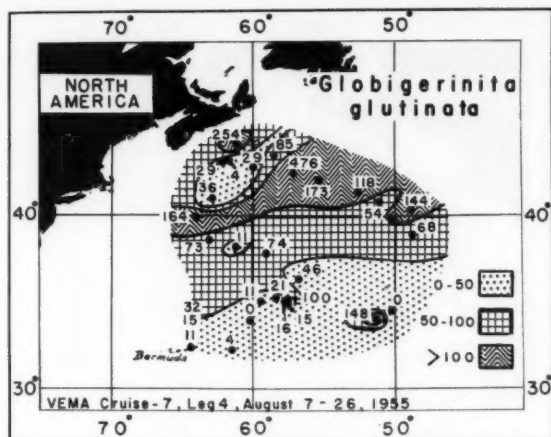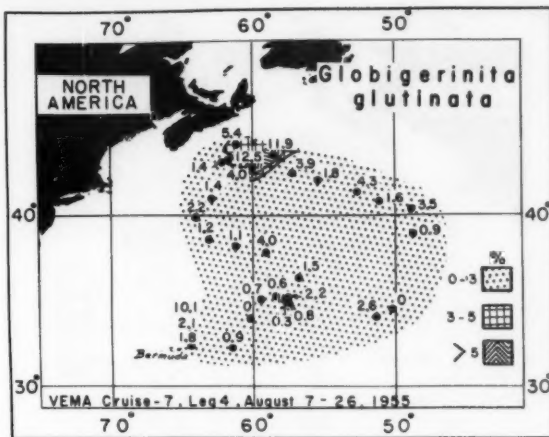TEXT-FIGURE 17

TEXT-FIGURE 18

TEXT-FIGURE 19

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TEXT-FIGURE 26

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TEXT-FIGURE 27

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TEXT-FIGURE 31
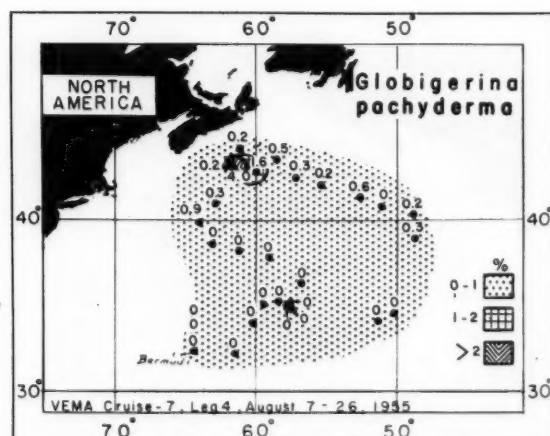
TEXT-FIGURE 32

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TEXT-FIGURE 36
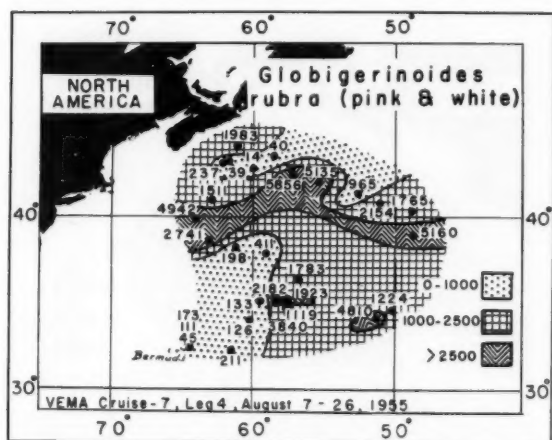
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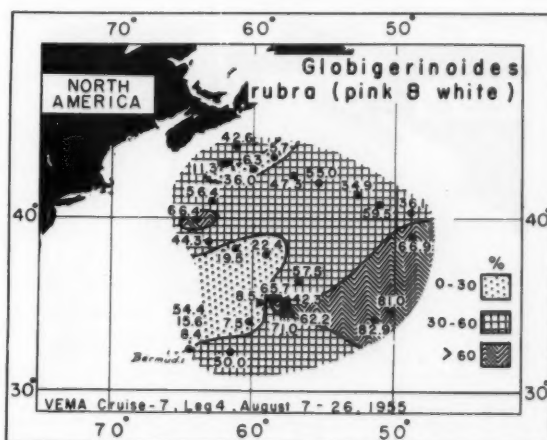
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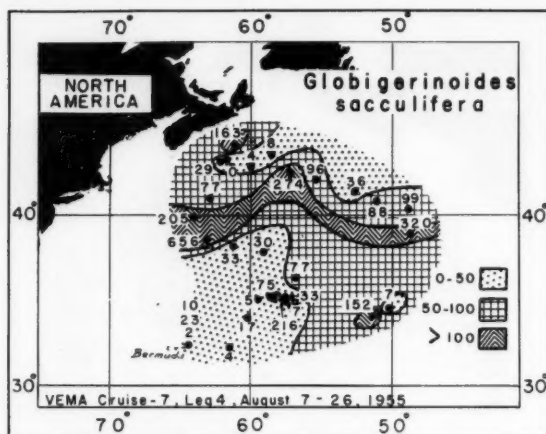
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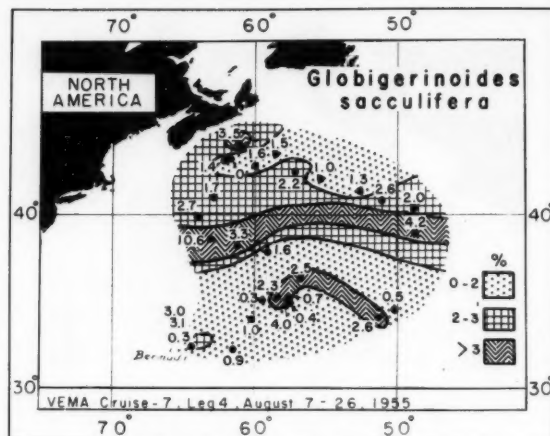
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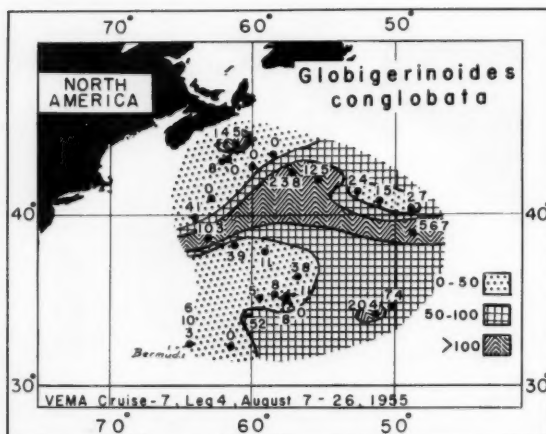
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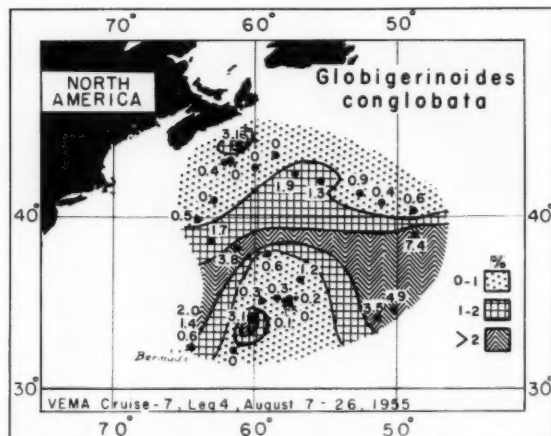
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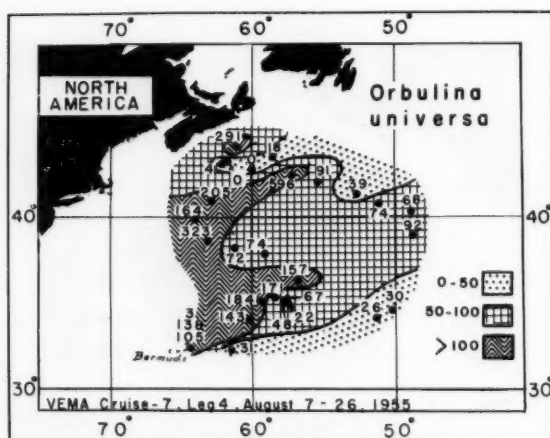
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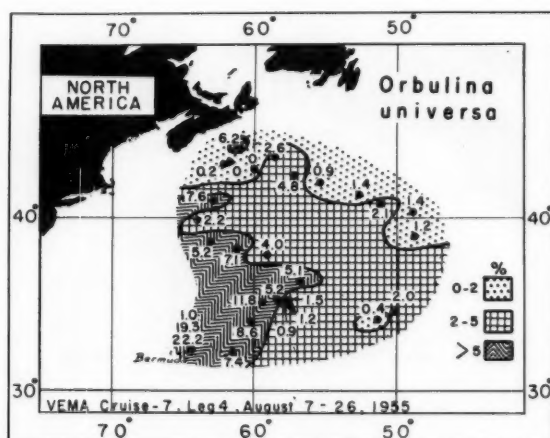
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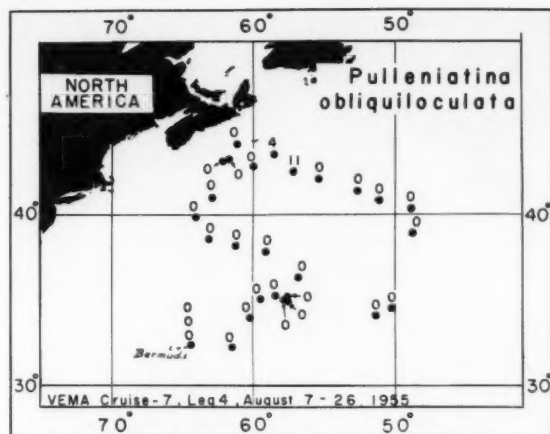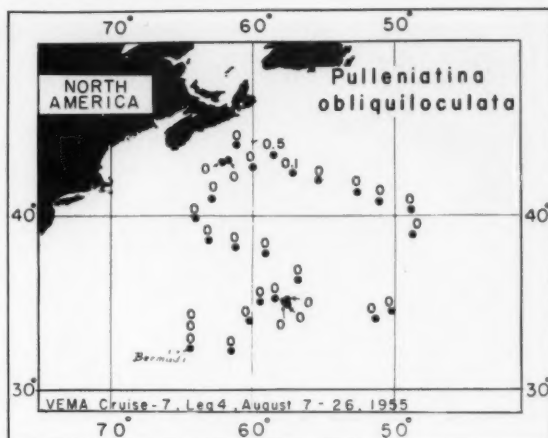
TEXT-FIGURE 45

TEXT-FIGURE 46
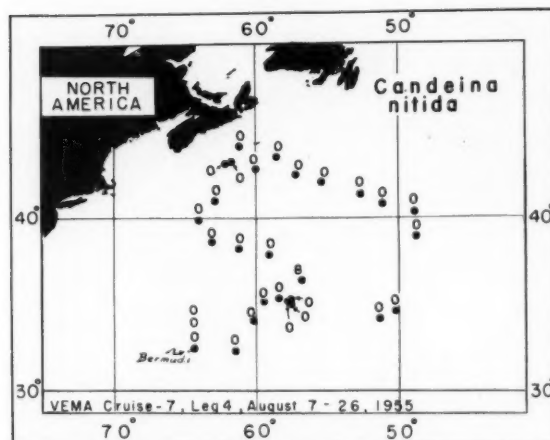
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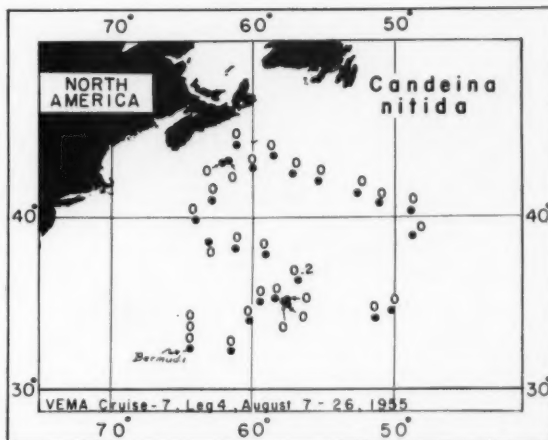
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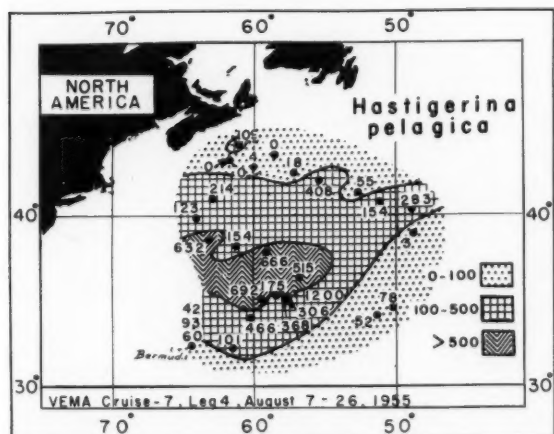
TEXT-FIGURE 49

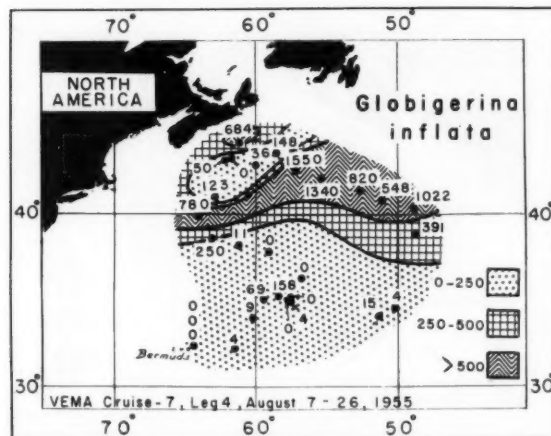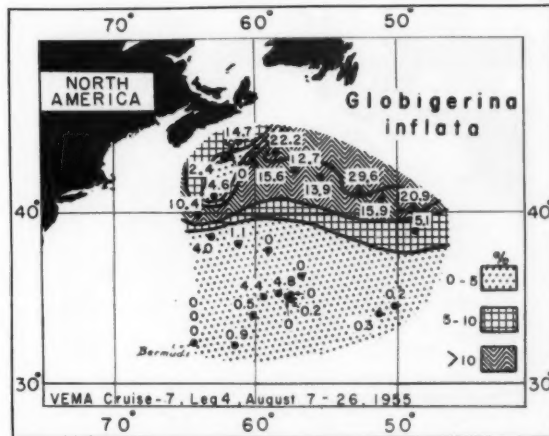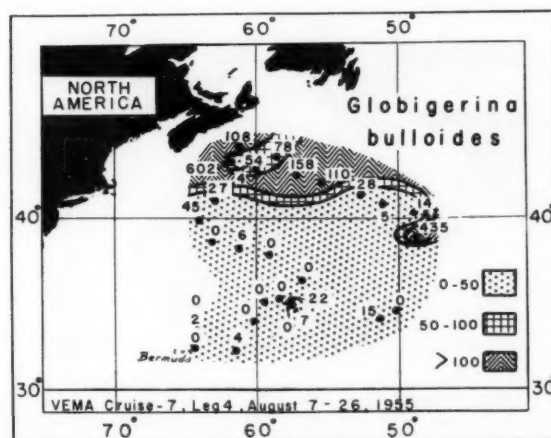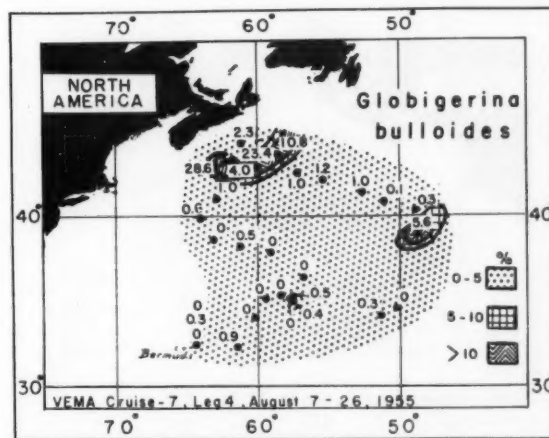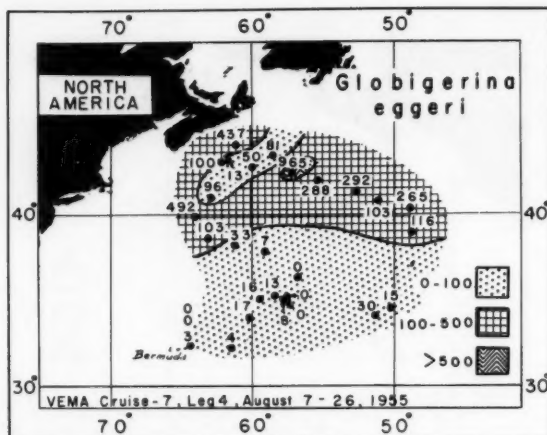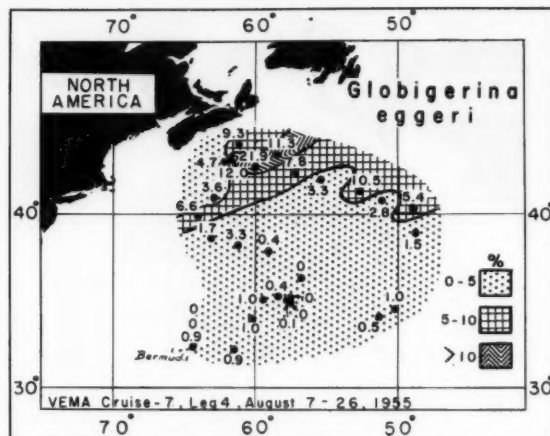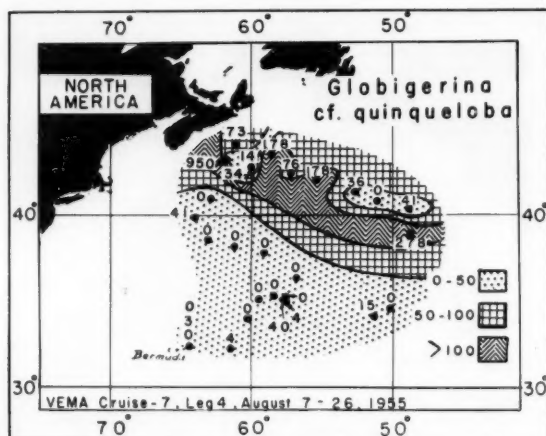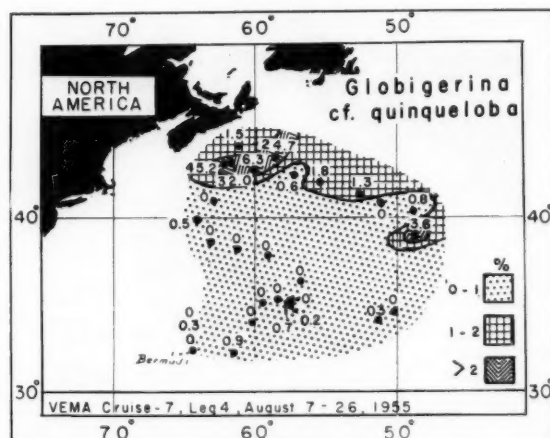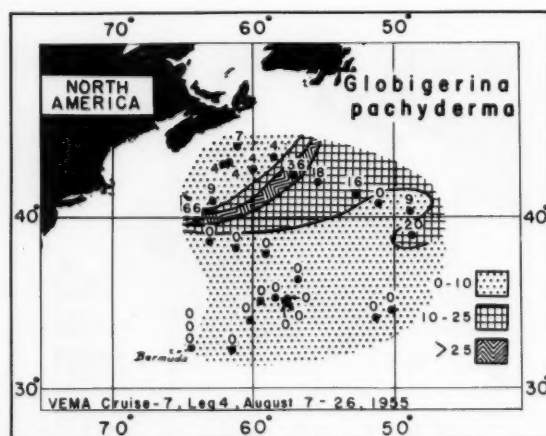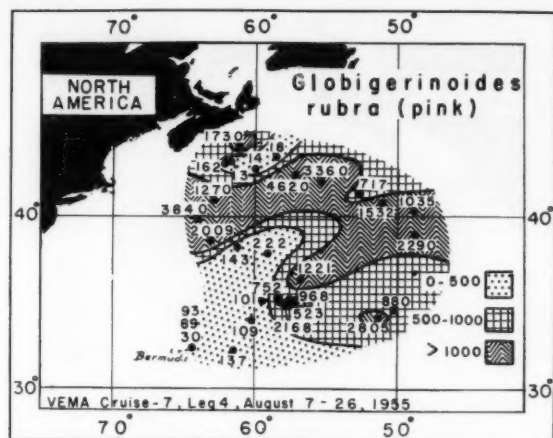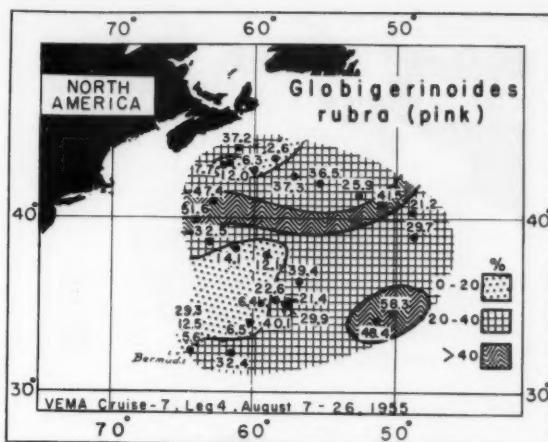TEXT-FIGURE 50

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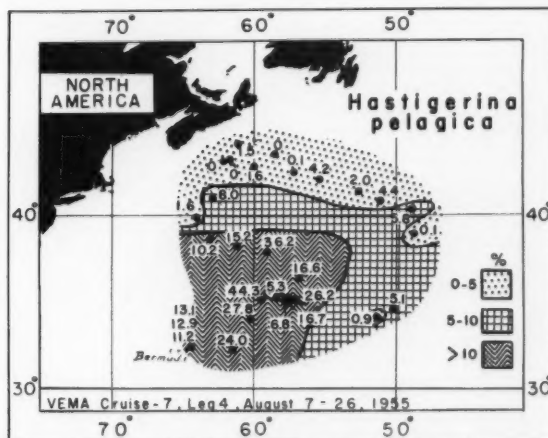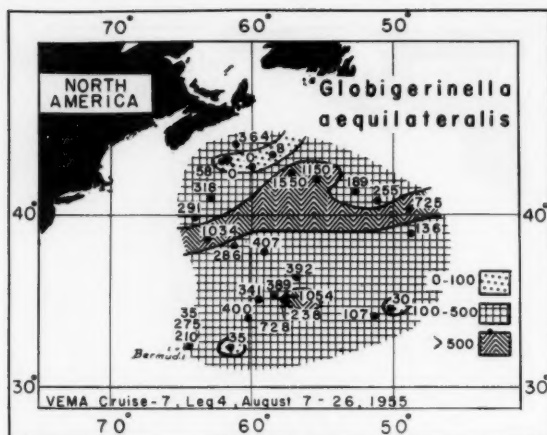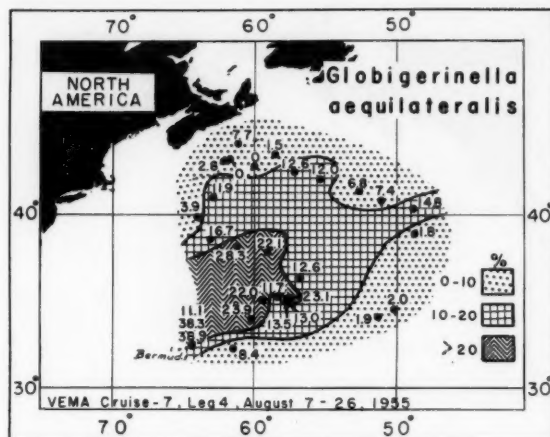
TEXT-FIGURE 51
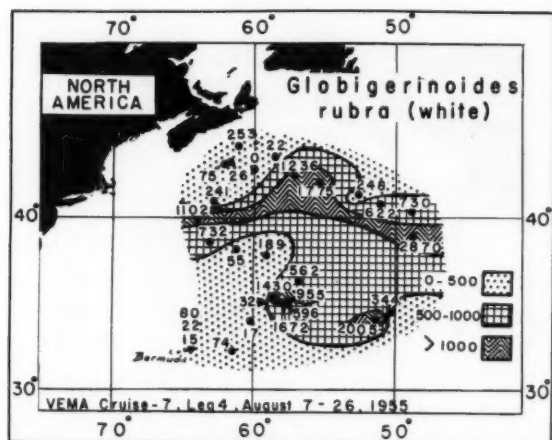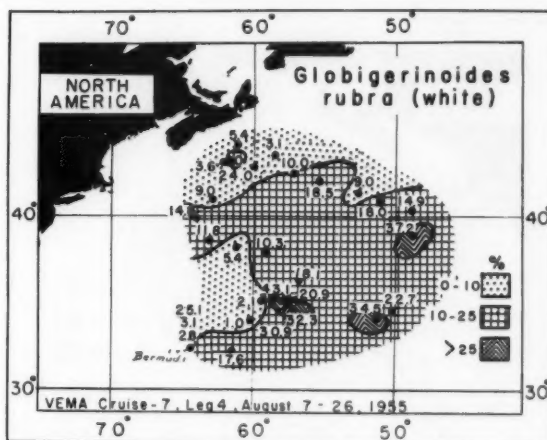

TEXT-FIGURE 52

PLATE 1

All figures × 52 unless otherwise noted.

1–3   *Globorotalia menardii* (d'Orbigny)
Station V8-3: lat. 17°05′ N., long. 68°59′ W.

4, 8   *Globorotalia hirsuta* (d'Orbigny)
Station NYZS-15: lat. 32°12′ N., long. 64°36′W.

5–7   *Globorotalia truncatulinoides* (d'Orbigny)
Station Tobis-1: lat. 32°15′ N., long. 64°39′ W.

9–11   *Globorotalia punctulata* (d'Orbigny)
Station V8-8: lat. 15°10′ N., long. 73°26′ W.

12–14   *Globigerina inflata* d'Orbigny
Station V11-SPT.2: lat. 39°32′N., long.72°22′W.

15–17   *Globigerina bulloides* d'Orbigny
Station Tobis-1: lat. 32°15′ N., long. 64°39′ W.;
× 78.

18   Morphological intergrade between *Globigerina bulloides* and *Globigerinella aequilaterali*-Station V7-26: lat. 40°56′ N., long. 62°59′W.

19–20, 27   *Globigerinella aequilateralis* (H. B. Brady)
Station V7-13: lat. 35°14′N., long. 59°30′W.:
19–20, symmetrical; 27, asymmetrical.

21–22   *Globigerina* cf. *quinqueloba* Natland
Station V7-27: lat. 42°53′ N., long. 62°07′
W.; × 78.

23–24   *Globigerina pachyderma* (Ehrenberg)
Station V7-26: lat. 40°56′ N., long. 62°55′W.

25–26   *Globigerinita glutinata* (Egger)
Station V11-SPT. 2: lat. 39°32′ N., long. 72°22′ W.

PLATE 2

All figures × 52 unless otherwise noted.

1–3   *Globigerina eggeri* Rhumbler
Station V8-3: lat. 17°05′ N., long. 68°59′ W.

4–6   *Pulleniatina obliquiloculata* (Parker and Jones)
Station V11-FL.3: lat. 38°06′N., long. 67°41′W.;
× 44: 4–5, mature; 6, juvenile.

7–12   *Globigerinoides conglobatus* (H. B. Brady)
Station V8-6: lat. 16°36′ N., long. 72°10′ W.:
7–10, mature; 11–12, juvenile.

13–15   *Globigerinoides sacculifer* (H. B. Brady)
Station V8-1: lat. 20°01′ N., long. 70°40′ W.

16–17   *Globigerinoides ruber* (d'Orbigny)
Station V8-8: lat. 15°10′ N., long. 73°26′ W.;
× 65.

18   *Orbulina universa* d'Orbigny
Station Tobis-1: lat. 32°15′ N., long. 64°39′ W.

19–20   *Candeina nitida* d'Orbigny
Station V8-6: lat. 16°36′ N., long. 72°10′ W.

21–22   *Hastigerina pelagica* (d'Orbigny)
Station V7-34: lat. 41°15′ N., long. 52°42′ W.

23   *Hastigerinella rhumbleri* Galloway
Station NYZS-700: lat. 32°12′N., long. 64°36′W.

PLATE 2
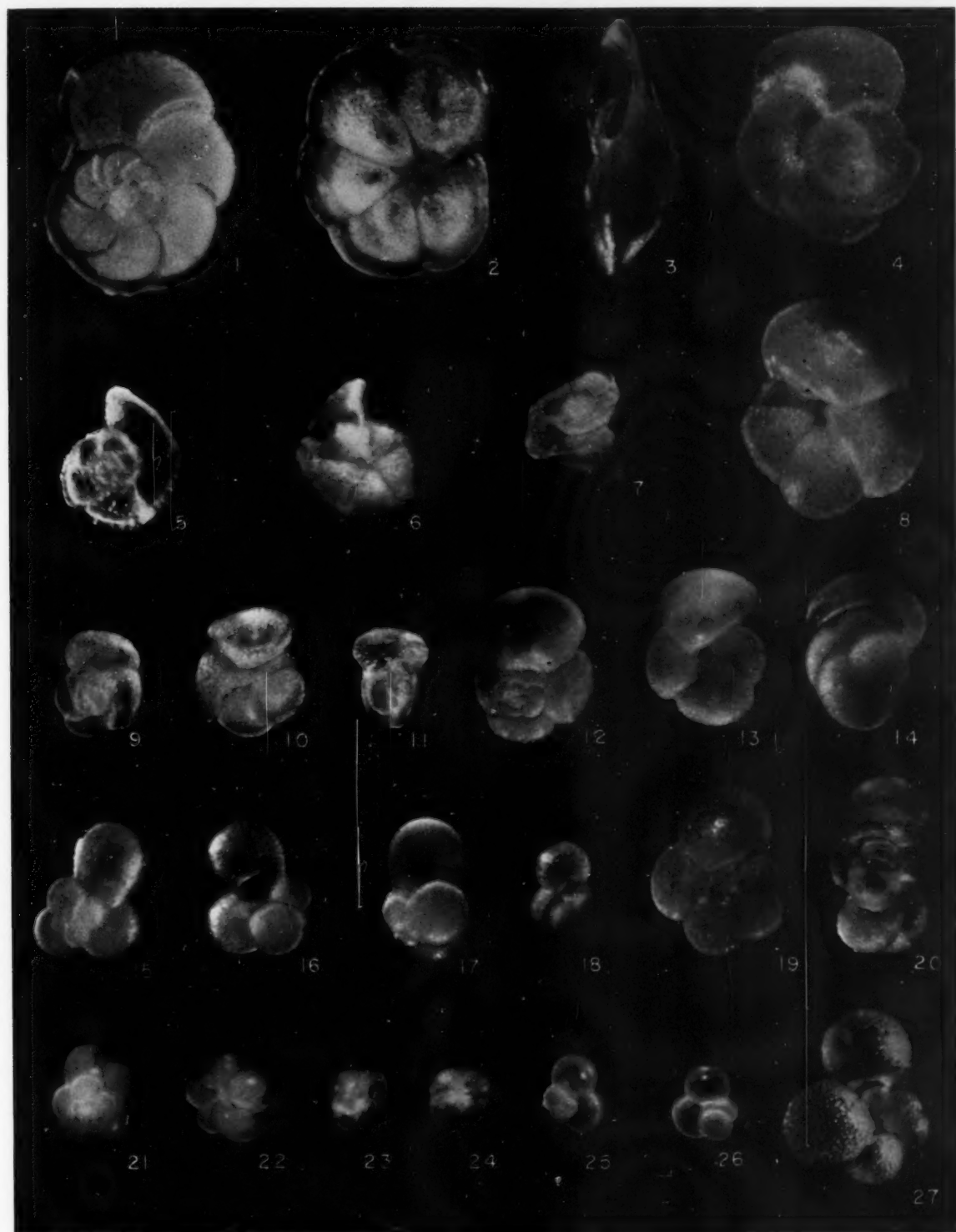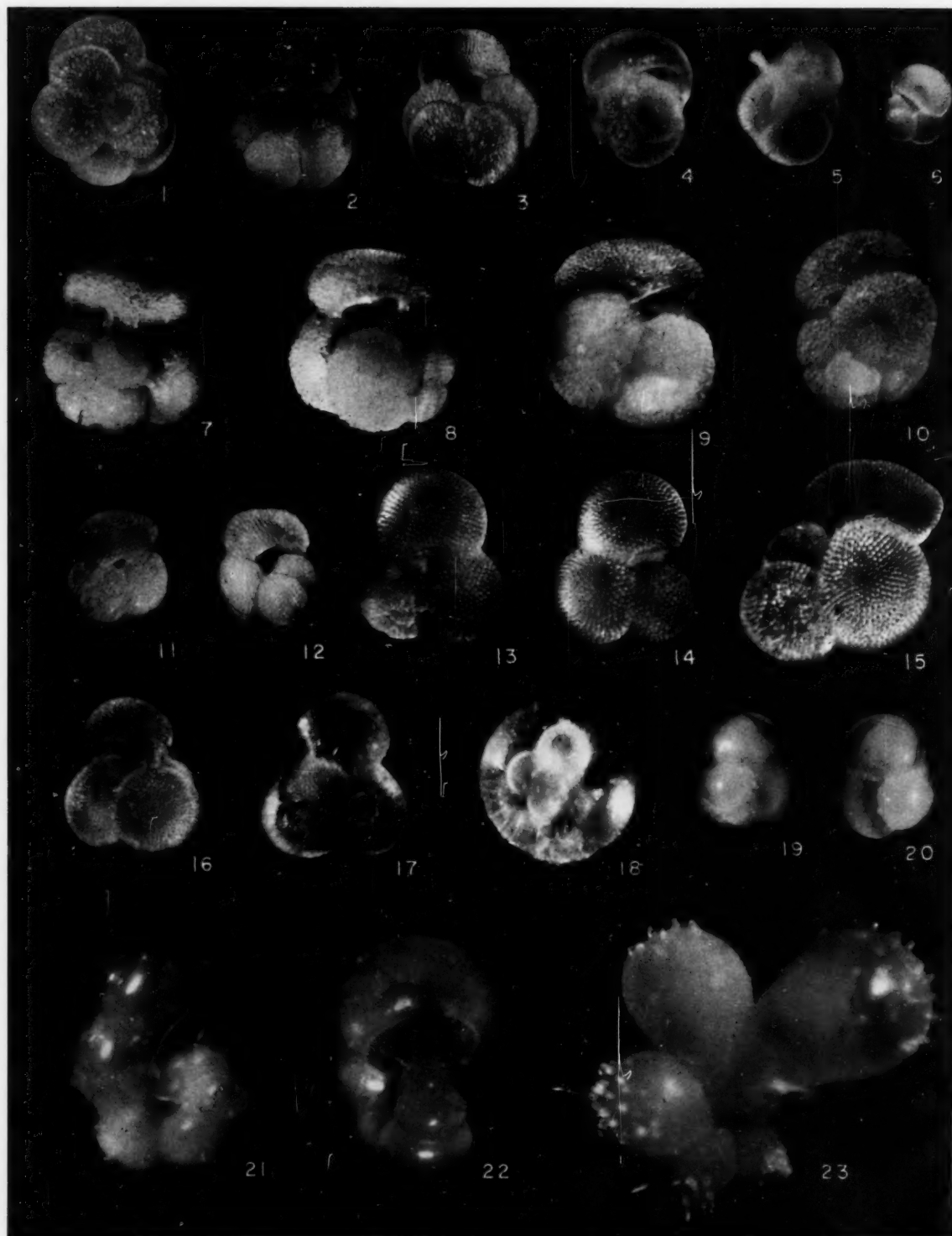
ABSTRACT: *Bottom samples from shallow to deep water were collected in Santa Monica Bay, California. The distributions of both living and dead foraminifera were determined. The majority of species living in the bay were found to have sharply restricted geographic and bathymetric ranges. Environmental factors such as current, nutrients, salinity, bottom sediments, and especially temperature are believed to control the distribution patterns of the benthonic species in the bay. The paleontological and oceanographic applications of this work are discussed, and four new forms are described.*

Foraminiferal ecology of Santa Monica Bay, California

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INTRODUCTION

The purpose of this study was to learn the distribution of both living and dead foraminifera in Santa Monica Bay (text-fig. 1), and to correlate trends in ecologic factors with biofacies. Such factors as temperature, current movement, nutrients, salinity, and bottom sediments are important components of a marine environment and should strongly influence all marine life, including one-celled organisms such as foraminifera. Information of this nature could be very useful in determining the environments under which oil-producing formations were deposited.

Location

Santa Monica Bay is a crescent-shaped embayment of about 250 square miles, and forms a large indentation in the coastline of southern California. The area sampled lies between latitudes 33°46′30″ and 34°01′50″ N., and between longitudes 118°23′43″ and 118°41′12″ W.

To the north, Santa Monica Bay is bounded by the Santa Monica Mountains, and to the south the bay is terminated by the Palos Verdes Hills. The flat sandy beaches of Santa Monica, Venice, Playa del Rey, El Segundo, Manhattan Beach, Hermosa Beach, Redondo Beach, and Hollywood Riviera form the eastern border of the bay. Sample locations within the bay are shown in text-figure 2.

General geology and physiography

The Santa Monica Mountains bordering the north end of the bay are an east-west trending range

attaining an elevation of 3000 feet. Outcropping rocks include Triassic metamorphics, Jurassic or Cretaceous crystallines, Cretaceous and Tertiary sediments, Tertiary lava flows, and marine sediments ranging in age from upper Pliocene to Pleistocene. Differential erosion due to jointing and to varying hardness of the rocks has resulted in an irregular shoreline along the northern part of Santa Monica Bay. Durrell (1954) has recently published a paper on the geology of the Santa Monica Mountains.

Along the eastern edge of the bay is the flat-lying Los Angeles Plain, which forms a rather low, straight shore. The sediments along this shore are mostly Pliocene shales, covered in many places by Pleistocene to Recent sand dunes and terrace deposits. An excellent report has been published recently on the geology of the Los Angeles Basin by Woodford, Schoellhamer, Vedder, and Yerkes (1954).

The Palos Verdes Hills, which constitute the southern boundary of Santa Monica Bay, rise to 1479 feet. The rocks making up the hills range in age from Jurassic(?) to Pleistocene, but the bulk of the sediments are Miocene shales, according to Woodring, Bramlette, and Kleinpell (1936). Some Miocene sills are also present on the south side of this rather complexly folded and faulted physiographic feature. The shoreline along the Palos Verdes Hills is irregular due to differential erosion of various rock types, and is somewhat similar in appearance to the shoreline along the base of the Santa Monica Mountains.

Samples taken by K. O. Emery in Santa Monica Bay indicate that the outcropping rocks are nearly all of Miocene age, except for a narrow strip paralleling the eastern shoreline from the city of Santa Monica

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* Now with the Texas Petroleum Company, Colombian Division, Bogotá, Colombia.

to Redondo Beach, along which Pliocene and Pleistocene sediments occur. Reworked foraminifera found in the writer's samples lend support to this age assignment, as a number of reliable Miocene and Pliocene guide fossils were mixed with Recent species from these areas.

Climate

Santa Monica Bay is in a region of semi-arid climate. The average yearly temperature is 62.3⁰ F., with a normal monthly high of 75.3⁰ F. in July and a normal low of 54.0⁰ F. in January. According to measurements taken on Santa Monica Pier by the Weather Bureau, the average annual precipitation is 9.70 inches. Virtually all of this precipitation usually falls during the months from September through April. The month of greatest rainfall is January, during which about half of the yearly quota falls. From March through September, rainfall in this area is negligible.

Rainfall and temperature data indicate that there should be no extreme changes in the salinity or temperature of the shelf water in Santa Monica Bay due to these causes. Therefore, with the exception of those organisms living in very shallow water, foraminiferal species in the bay need not be especially eurythermal nor euryhaline.

PREVIOUS WORK

Some of the first work done on foraminiferal ecology in this area was that of Moyer (1929). She compared several species of fossil foraminifera from the Lomita Quarry, San Pedro, California, with Recent specimens living off the Pacific coast.

Natland (1933) investigated samples taken across the San Pedro Channel, from San Pedro Bay to Catalina Island. He established five faunal zones, containing foraminiferal species inhabiting waters ranging from shallow tide-pools to a depth of 8000 feet. Natland felt that temperature was probably the most important restricting influence on foraminiferal distribution.

A study of three profiles was conducted by Bandy (1953*a*, *b*). These profiles extended seaward from San Francisco, Point Arguello, and San Diego. Bandy noted that many species were sharply restricted by water depth in each profile, but that several identical species, both shallow and deep-water types, had different depth ranges from north to south. He believed that, although temperature was the primary ecological factor governing shallow-water distribution of foraminifera, other factors perhaps exerted more control over deep-water species living in an environment where temperature

has little or no variation. Five depth zones were established between 0 and 12,000 feet, based upon the distribution of several characteristic foraminiferal species.

Walton (1955), in his work on the ecology of foraminifera in Todos Santos Bay, Baja California, stained the bottom samples with rose bengale, and made accurate counts of living as well as dead specimens. He found that the living individuals of a species occupy a narrower depth range than the dead individuals. Walton reported that variations in depth, temperature, food, and type of sediment are the principal factors producing restricted geographic and bathymetric distribution patterns of foraminiferal species. Four geographic assemblages were postulated. These were designated as Outer Bay, Middle Bay, Inner Bay, and Marginal Bay facies. He also established the following four depth facies: Zone 1, 0–30 fathoms; zone 2, 30–50 fathoms; zone 3, 50–100 fathoms; zone 4, deeper than 350–400 fathoms.

The greatest number of living foraminifera were found in the seasons of warmer water-temperatures, during the late spring and summer months. It was also discovered that the maximum abundance of benthonic foraminifera occurs between 20 and 50 fathoms.

METHODS

Seventy bottom samples were collected in Santa Monica Bay between June 15 and September 15, 1955. The samples from depths between $6\frac{1}{2}$ and 460 fathoms were obtained by means of the Hayward grab, when possible, or by the smaller snapper sampler whenever the larger sampler could not be used because of lack of time or available manpower. The Hayward grab takes a sample with a surface area of 450 square inches, and the snapper sampler has an area of about 24 square inches.

Inasmuch as the primary objective was to find living foraminifera, the surface sediment from each sample was carefully removed and preserved in isopropyl alcohol. A short time after the preserved samples were brought to the laboratory, a protoplasm stain known as rose bengale was added. This reddish-pink solution stains the protoplasm of the living specimens a bright red, but does not alter the white tests of dead or reworked foraminifera.

When dry, the samples were weighed to the nearest tenth of a gram. Knowledge of the weight of each sample was needed for a later calculation of the number of foraminifera per gram of sediment. Approximately 100 grams of each sample were then

TEXT-FIGURE 1

MAP SHOWING LOCATION OF SANTA MONICA BAY

washed through a 250-mesh screen having a screen opening of 0.061 mm. Carbon tetrachloride was used to float off the foraminifera from the coarse sediment remaining on the screen. The condensed foraminiferal samples were then placed in stoppered glass tubes for later study.

In order to assure a representative foraminiferal species count, each sample was run through a micro-splitter as many times as was necessary to reduce the number of individuals sufficiently to permit easy manipulaotin and accurate identification on the counting grid. After brief inspection, all of the benthonic and planktonic specimens on alternate squares or rows were counted until at least 300 or more benthonic specimens were recorded. From this information, the relative percentage of every foraminiferal species in each sample was computed.

Exhaustive experimentation has indicated that when 300 benthonic individuals are counted, the relative percentages change very little when an additional thousand specimens are counted and the percentages recalculated.

After the first percentage count was completed, a second count was made to determine the number of living or reddish-stained specimens which were trapped in each sample. It was found that the living foraminifera make up a very small fraction of any sample, and every stained individual was therefore counted. This was done by spreading an entire sample on a cobalt glass plate and examining every specimen.

OCEANOGRAPHY

Water temperature

Several hundred water-temperature measurements were taken within and beyond the limits of the bay, between June, 1955, and April, 1956, by the Santa Monica Bay Project. At all stations, the temperature readings were recorded with thermometers of the reversing type. The results were plotted to show the way in which temperature decreases with increasing depth. As is shown in text-figure 3, the water temperature varies from a maximum of 22^0 C. at the beach down to a minimum of about 5^0 C. in the deepest zones sampled. Surface water reflects the greatest seasonal fluctuation, between 13.50 C. and 22.0^0 C. This temperature fluctuation decreases rather steadily with increasing depth until it becomes very slight or non-existent.

Bathythermograms show a well developed thermocline in the bay. This abrupt temperature-change at a depth of about 10 fathoms indicates the presence of two separate water layers on the shelf. A warm, well mixed layer of water approximately 60 feet thick overlies a colder-water layer with a more normal temperature gradient. From this information it is evident that foraminifera living in shallow water from 0 to 15 fathoms must be eurythermal enough to withstand a temperature fluctuation up to 10^0 C., whereas deeper-water species need not adapt to as great a range of changing temperatures.
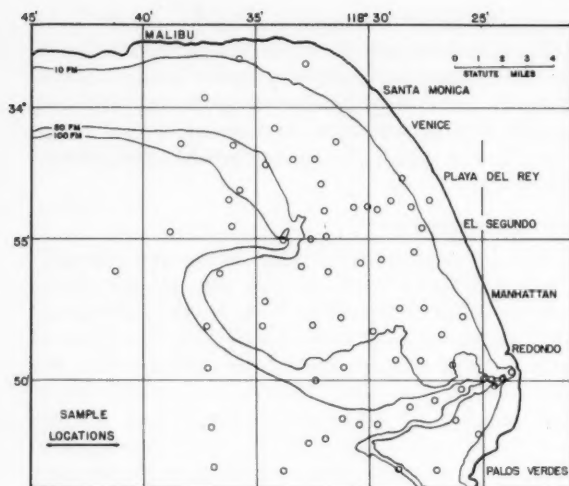
TEXT-FIGURE 2

INDEX TO SAMPLE LOCATIONS ON THE SHELF, IN THE SUBMARINE CANYONS, AND ON THE SLOPE

TABLE 1

SAMPLE LOCATIONS

The depths and locations of the seventy samples from Santa Monica Bay used in this study are listed here. They are arranged numerically by Hancock Foundation station numbers.

Station number	Depth (in fathoms)	Latitude	Longitude
3099	16	33°56'23"	118°28'17"
3100	31	33°52'40"	118°27'51"
3101	36	33°50'11"	118°23'43"
3102	95	33°49'51"	118°24'55"
3103	150	33°49'37"	118°26'05"
3105	223	33°48'46"	118°28'07"
3106	300	33°48'14"	118°30'30"
3107	300	33°47'36"	118°32'54"
3110	270	33°53'47"	118°41'12"
3111	235	33°55'18"	118°38'45"
3112	181	33°55'30"	118°36'07"
3113	113	33°55'00"	118°33'48"
3161	12.5	33°47'56"	118°25'12"
3163	60	33°49'53"	118°24'39"
3164	80	33°49'52"	118°24'37"
3165	22	33°50'03"	118°24'06"
3166	196	33°49'15"	118°27'14"
3167	280	33°48'16"	118°29'38"
3168	315	33°47'40"	118°32'10"
3169	380	33°46'33"	118°33'42"
3170	460	33°46'38"	118°37'02"
3171	425	33°48'10"	118°37'04"
3222	110	33°46'30"	118°28'42"
3223	165	33°48'27"	118°31'11"
3225	40	33°48'30"	118°26'10"
3226	41	33°50'33"	118°26'15"
3227	65	33°50'40"	118°28'45"
3228	60	33°50'30"	118°31'04"
3233	36	33°52'28"	118°31'13"
3234	40	33°52'24"	118°28'40"

Station number	Depth (in fathoms)	Latitude	Longitude
3235	15	33°52'20"	118°25'50"
3239	10.5	34°01'50"	118°35'38"
3240	27	34°00'20"	118°37'15"
3241	95	33°58'36"	118°38'22"
3242	75	33°58'35"	118°36'00"
3244	20	33°58'40"	118°31'24"
3246	9.5	33°56'33"	118°27'24"
3247	18	33°56'32"	118°29'06"
3250	105	33°56'33"	118°36'10"
3325	34.5	33°55'06"	118°31'57"
3326	37	33°55'03"	118°32'35"
3328	6.5	34°01'33"	118°32'52"
3330	60	33°57'55"	118°34'40"
3331	32	33°57'59"	118°33'27"
3332	28	33°58'05"	118°32'14"
3336	12	33°57'20"	118°28'36"
3339	28.5	33°57'05"	118°32'10"
3342	105	33°56'50"	118°35'43"
3346	32	33°56'05"	118°32'04"
3348	24	33°56'15"	118°29'42"
3351	28.5	33°54'18"	118°29'30"
3353	33	33°54'07"	118°31'52"
3354	39	33°54'02"	118°33'03"
3355	32	33°56'32"	118°27'03"
3385	65	33°50'00"	118°32'23"
3387	50	33°51'59"	118°37'10"
3388	40	33°52'01"	118°34'48"
3389	38	33°52'03"	118°32'33"
3395	24	33°56'15"	118°30'00"
3400	220	33°50'30"	118°37'06"
3422	50	33°53'47"	118°36'34"
3473	41	33°52'54"	118°34'38"
3476	44	33°50'37"	118°27'47"
3486	17	33°54'50"	118°28'03"
3497	31	33°54'11"	118°30'18"
3530	34	33°51'54"	118°29'54"
3681	35	33°51'33"	118°26'54"
3697	30.5	33°59'10"	118°34'16"
3715	26	33°56'19"	118°30'32"
3721	13.5	33°55'31"	118°27'45"

Salinity

From June, 1955, to April, 1956, several hundred water samples were collected for salinity determinations. Samples from below the surface were taken with Nansen bottles. These sampling devices are lowered to the desired depth and then tripped with a brass messenger which slides down the cable. Tripping the device automatically seals approximately one quart of sea water inside the container, which is then brought to the surface. Salinity determinations were carried out in the laboratory.

Salinity increases at a fairly constant rate below a depth of about 10 fathoms. From 0 to 10 fathoms, salinities vary, and display a fluctuation between 32.0 and 33.6 parts per thousand. This condition is caused by evaporation of surface water and to some local extent by the drainage of fresh water into the bay. Sources of fresh water are Ballona Creek, streams in the Santa Monica Mountains, rainfall,

TEMPERATURE VS. DEPTH
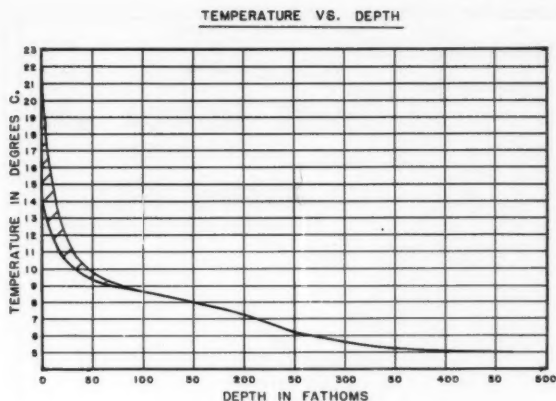
TEXT-FIGURE 3

TEMPERATURE VERSUS DEPTH IN SANTA MONICA BAY

SALINITY VS. DEPTH

TEXT-FIGURE 4

SALINITY VERSUS DEPTH IN SANTA MONICA BAY

and chlorinated sewage effluent from the Hyperion sewage outfall.

Below 10 fathoms, as is shown in text-figure 4, salinity increases steadily with depth. From the shallowest to the deepest zone sampled, the salinity of the water changes only about one part per thousand. A variation of such small magnitude appears to indicate that salinity could not be an important agent restricting foraminiferal distribution in the area studied.

Currents

Currents are very important in keeping the water of Santa Monica Bay at a fairly constant salinity. Driftcard movements plotted by personnel of the Santa Monica Bay Project indicate that the surface currents are activated by dominant westerly winds. These winds drive the water into the central part of the bay, where it piles up and is then forced out through the northern and southern ends of the bay.

Bottom currents were investigated with an Ekmann current meter, which was in operation while the ship was anchored at stations throughout the area. The bottom currents were found to be moving at less than 0.3 knots, and to be continually changing direction. No definite trends could be plotted, but it is evident that the currents circulate enough to keep the environment rather uniform.

MARINE GEOLOGY
Bottom topography

The part of the continental shelf that forms the bottom of Santa Monica Bay is thought by Shepard and Macdonald (1938) to be a wave-cut terrace developed during Pleistocene time, when the sea level was a great deal lower than at the present time.

The rather flat surface of the shelf, together with the presence of gravel on the outer part of the shelf and along the sides of the submarine canyons, supports this theory. More recent work, done by the Santa Monica Bay Project, indicates, however, that the area of rock and gravel represents the remnants of what was once an island in the bay.

As can be seen in text-fig. 5, the shelf is cut by two westward-trending submarine canyons, which are named for the beach cities nearest to the heads of the canyons. The northernmost has been named Santa Monica Canyon, and the southernmost is called Redondo Canyon. Redondo Canyon cuts to within a few hundred feet of the shoreline. From its head, the canyon extends out from the shore about 8 miles, where it reaches a depth of approximately 350 fathoms. Santa Monica Canyon begins about 5½ miles from the coast and extends seaward to a depth of 450 fathoms.

Of interest is the fact that both canyons have more gentle slopes on the north side than on the south side. The bottoms of both canyons have rather uniform seaward slopes, which tend to increase in gradient below the 50-fathom contour line. The steeper gradients continue down to more than 350 fathoms, where the canyon bottoms level out.

The 50-fathom or 300-foot contour line represents the approximate outer edge of the continental shelf in the bay. Detailed fathometer tracings indicate that the shelf is generally flat, with a few minor surface irregularities.

Both canyons influence the bottom-sediment pattern, and are thought to have caused displacement of shallow material into deeper zones by occasional turbidity flows of sediments down the canyons. In opposition to the turbidity-flow theory is the fact that foraminiferal species living in the narrow, V-shaped Redondo Canyon display well defined
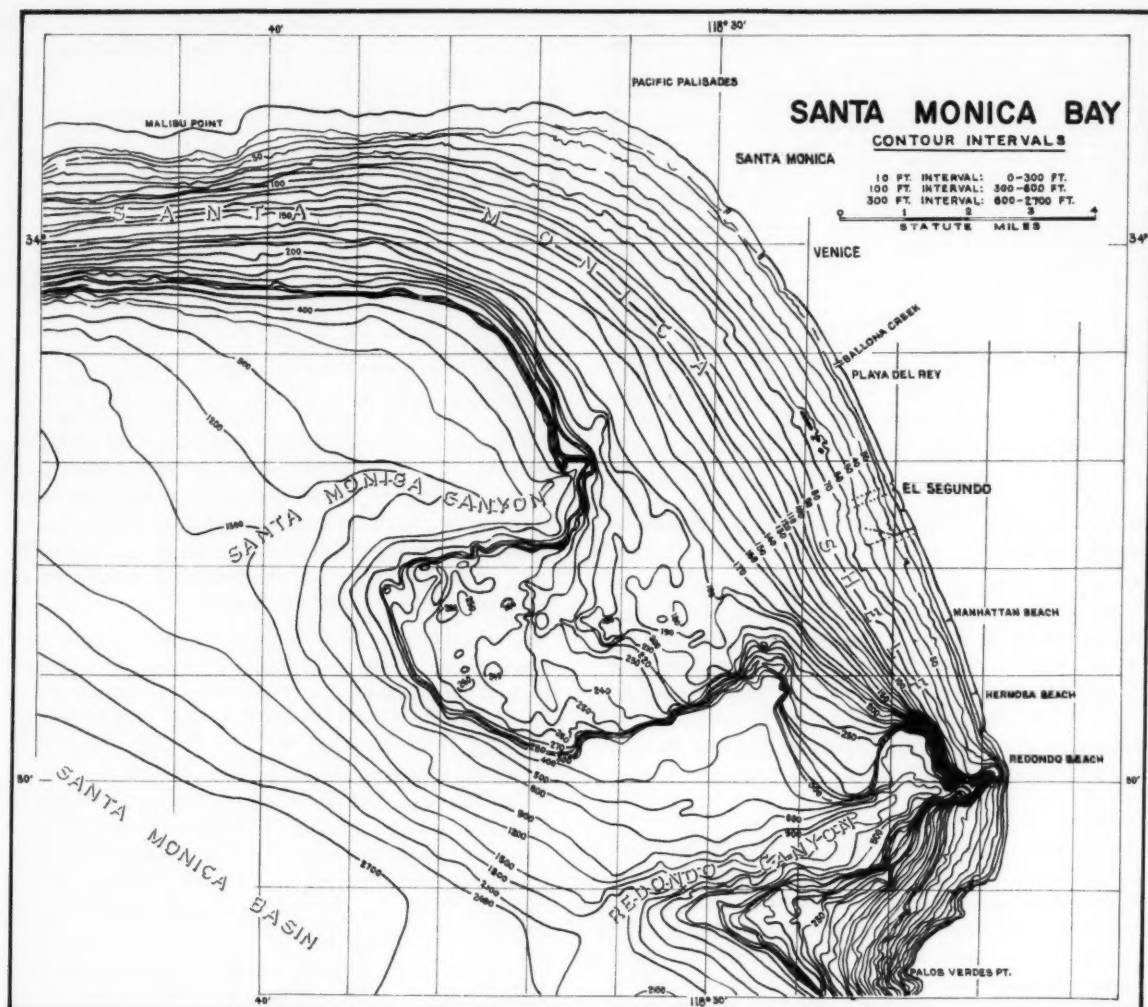
TEXT-FIGURE 5

MAP SHOWING BOTTOM TOPOGRAPHY OF SANTA MONICA BAY

depth ranges and do not exhibit a mixed or displaced distribution.

Bottom sediments

In Santa Monica Bay, the median diameters of the sediments decrease outward from the shore on the inner shelf area. On the outer part of the shelf, the distribution of coarse and fine sediments is patchy, with the occurrence of a great deal of gravel and rock from 6 to 8 miles offshore on the shelf between the two submarine canyons. Irregular distribution of silt, sand, gravel, and rock, as shown in text-figure 6, illustrates this unusual situation on the bottom of the bay.

As can be seen on the sediment map, coarse sediments are found in close proximity to fine sediments at many points. According to Shepard and Macdonald (1938), the coarse sediments located several miles offshore are thought either to have been derived from underlying rock outcrops or to have been transported to the area during a time of lower sea level.

More recent work done by the Santa Monica Bay Project (1955–1956) indicates that the rocky area on the shelf may perhaps be the remnants of an old island, which has long since been eroded away. As the sediments appear to grade from coarse to fine
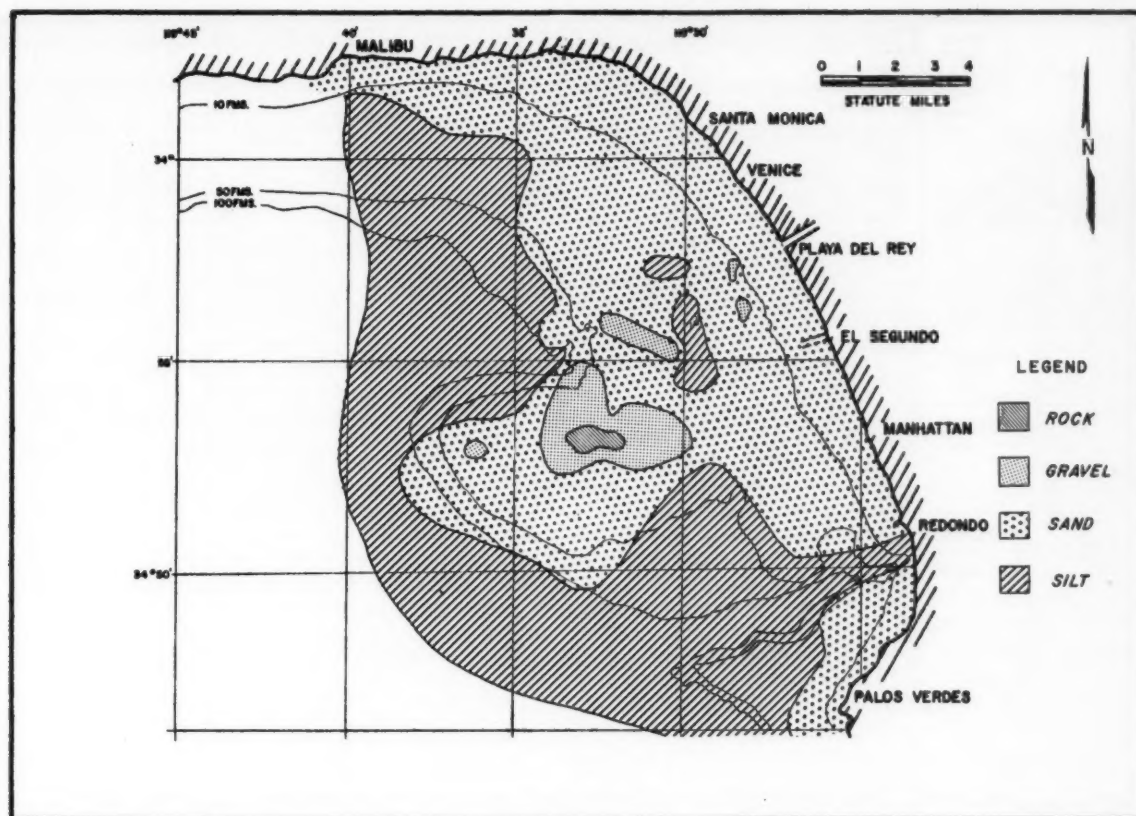
TEXT-FIGURE 6
BOTTOM SEDIMENTS OF SANTA MONICA BAY

with increasing distance from the rocky area, this could be a very plausible solution to the strange sediment-distribution pattern. The general trend of the faults in this area also lends support to the island theory, suggesting the presence of an uplifted fault block where the island would have been.

The sediment-distribution pattern could be an important factor in the geographic distribution of certain foraminiferal species in the bay. This might be true of some species of *Cassidulina*, which show a definite affinity for the rock and gravel area, where they dominate the foraminiferal assemblage. Arenaceous foraminifera would have to live in an environment supplying the types of sand or silt grains essential for the construction of their tests. Some species are known to display a high degree of selectivity with regard to the shapes and sizes of their building materials.

Rock outcrops

Rock outcrops occur along the sides of the two submarine canyons as well as on the surface of the shelf between the canyons. Samples broken off and recovered by the dredge are primarily siliceous shales of Miocene age. These shales are correlative in age and lithology with the Altamira shale which crops out in the nearby Palos Verdes Hills.

FORAMINIFERA

General remarks

As can be seen from the chart (text-fig. 7), nearly one hundred benthonic species from Santa Monica Bay were identified and plotted according to their percentages. In some cases, species that amounted to insignificant percentages when plotted alone were plotted collectively under their generic name.

On the chart, the samples are arranged in order of increasing depth, from 6.5 to 480 fathoms. Numbers on the chart indicate the relative percentages of individual species found in each of the seventy samples. Depth ranges of all species and their zones of greatest abundance become obvious upon close examination of the chart.

o = UNDER 1%

SAMPLE NUMBERS

DEPTH IN FATHOMS

Species	
TROCHAMMINA PACIFICA	
DISCORBIS MONICANA	
EGGERELLA ADVENA	
ELPHIDIUM TRANSLUCENS	
BULIMINELLA ELEGANTISSIMA	
ALVEOLOPHRAGMIUM ADVENA	
ALVEOLOPHRAG. COLUMBIENSE ROBUSTA	
PROTEONINA ATLANTICA	
BUCCELLA FRIGIDA	
FISSURINA LUCIDA	
BOLIVINA VAUGHANI	
BULIMINA DENUDATA	
NONIONELLA BASISPINATA	
NONIONELLA MIOCENICA STELLA	
QUINQUELOCULINA SPP.	
TRILOCULINA SPP.	
CIBICIDES LOBATUS	
CIBICIDES MCKANNAI SUPPRESSUS	
LAGENA SPP.	
POLYMORPHINA SPP.	
ANGULOGERINA ANGULOSA	
BOLIVINA ACUMINATA	
TEXTULARIA CONICA MONICANA	
REOPHAX COMMUNIS	
BOLIVINA PACIFICA	
GAUDRYINA ARENARIA	
GOESELLA FLINTII	
REOPHAX SCORPIURUS	
STREBLUS TEPIDUS	
SIPHONODOSARIA SP.	
ROTORBINELLA VERSIFORMIS	
FRONDICULARIA GIGAS	
CASSIDULINA MINUTA	
BOLIVINA SUBADVENA SULPHURENSIS	
BULIMINA AURICULATA	
BULIMINA SUBACUMINATA	
CASSIDULINA TORTUOSA	
PULLENIA SALISBURYI	
VIRGULINA SEMINUDA	
CASSIDULINA SUBGLOBOSA	
CASSIDULINA LIMBATA	
HANZAWAIA BASILOBA NITIDULA	
NONIONELLA MONICANA	
TEXTULARIA SCHENCKI	
BOLIVINA ACUTULA	
BOLIVINA DECUSSATA	
CANCRIS SAGRA	
CASSIDULINA CALIFORNICA	
PLANULINA ARIMINENSIS	
PYRGO SP.	
ELPHIDIUM ARTICULATUM	
CIBICIDES REFULGENS	
EPISTOMINELLA BRADYANA	
BOLIVINA PERRINI	
LAGENONODOSARIA CATESBYI	
TEXTULARIA EARLANDI	
ELPHIDIUM TUMIDUM	
REOPHAX GRACILIS	
SIGMOMORPHINA TORTA	
CIBICIDES FLETCHERI	
GAUDRYINA ATLANTICA PACIFICA	
HANZAWAIA BERTHELOTI	
ROTORBINELLA LOMAENSIS	
UVIGERINA JUNCEA	
UVIGERINA PEREGRINA	
UVIGERINA HOOTSI	
ANGULOGERINA BAGGI	
ASTRONONION SIDEBOTTOMI	
BOLIVINA SINUATA	
CASSIDULINOIDES BRAZILIENSIS	
DENTALINA SPP.	
BOLIVINA INTERJUNCTA	
CASSIDULINA DELICATA	
GLOBOBULIMINA PACIFICA	
NONIONELLA LABRADORICA	
SUGGRUNDA ECKISI	
BOLIVINA ARGENTEA MONICANA	
BOLIVINA SPISSA	
EPISTOMINELLA SMITHI	
UVIGERINA PROBOSCIDEA	
BOLIVINITA MINUTA	
CHILOSTOMELLA OVOIDEA	
EPISTOMINELLA PACIFICA	
LOXOSTOMA PSEUDOBEYRICHI	
VALVULINERIA ARAUCANA	
BULIMINELLA TENUATA	
VIRGULINA SCHREIBERSIANA	
VIRGULINA COMPLANATA	
BULIMINA AFFINIS	
CASSIDULINA TRANSLUCENS	
CASSIDULINOIDES CORNUTA	
VIRGULINA INAEQUALIS	
PLANULINA ORNATA	
GYROIDINA GEMMA	
BULIMINELLA DUBIA	
BULIMINA SPINIFERA	

TEXT-FIGURE 7

CHART SHOWING RELATIVE PERCENTAGES OF ALL SPECIES COUNTED

TEXT-FIGURE 8

PERCENTAGE DISTRIBUTION PATTERN OF *Trochammina pacifica*

In order to determine the geographic and bathymetric ranges of the abundant foraminiferal species known to be living in Santa Monica Bay, several individual species and groups of similar species were isolated for special study. To show this in the clearest way possible, each selected species or group was plotted by relative percentage of the foraminiferal assemblage in their sample locations on a map of the bay. These numbers were then contoured to show the area of greatest abundance, surrounded by zones of decreasing population density.

Several interesting distribution patterns became apparent. Certain species seemed to prefer shallow water along the coast, some were found to like rocky areas, and others inhabited the submarine canyons, exclusively. For convenience, the discussion of the characteristic species which follows starts with the shallow-water types.

Shallow-water species

Trochammina pacifica is an arenaceous species known to inhabit nearshore waters along the west coast of the United States. In Santa Monica Bay, this species, as can be seen in text-figure 8, reaches its greatest abundance, making up 82 per cent of the assemblage, at a point about 2 miles offshore, in 17 fathoms of water. This species was found to range from the littoral zone to a depth of 41 fathoms on the shelf. A few individuals were found in somewhat deeper water at the head of Redondo Canyon, but might have been reworked or displaced with sediment down the steep sides of the canyon. As can be seen from the contoured distribution map (text-fig. 8), the greatest abundance of this species lies just beyond the end of the Hyperion sewage outfall at El Segundo. With increasing distance from this point in all directions, *Trochammina pacifica* makes up less and less of the foraminiferal assemblage.

According to this distribution pattern, it appears possible that the nutrients and fresh water from the outfall help to provide a favorable environment for this species, whereas other shallow-water species living in the bay prefer a more natural marine environment. Other factors characterizing the dis-
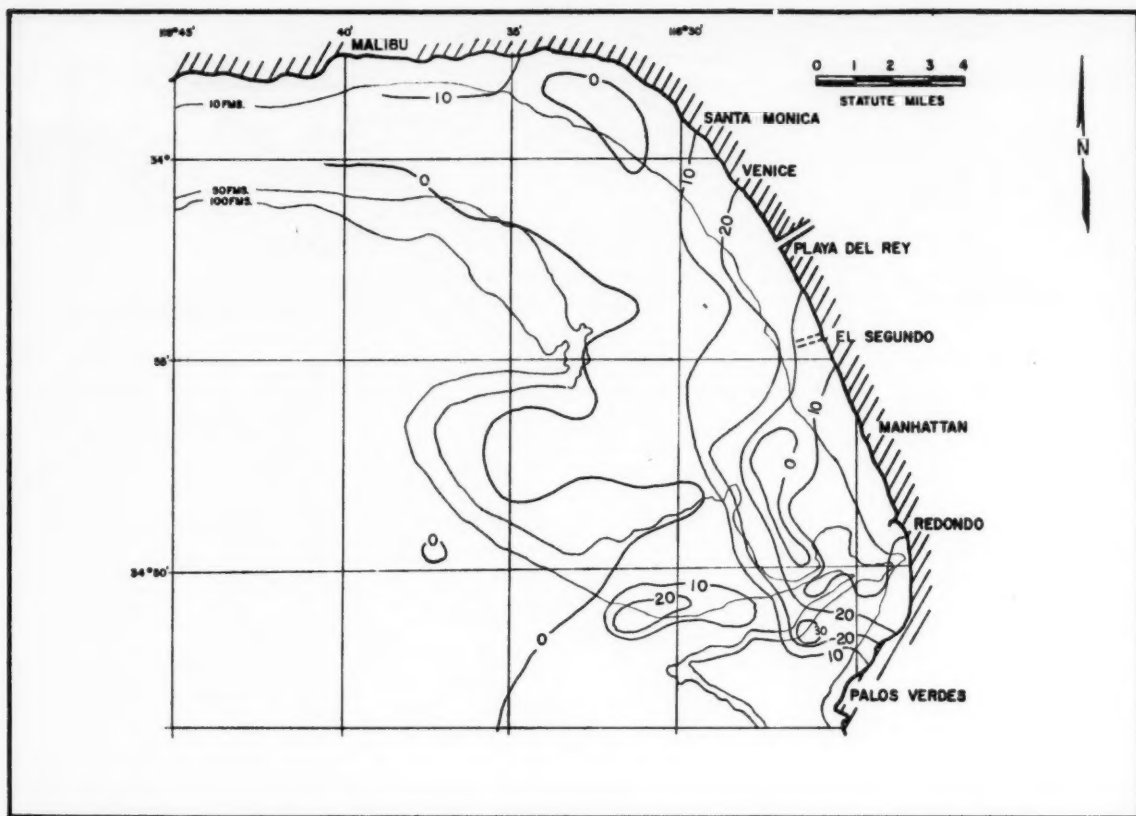
TEXT-FIGURE 9

PERCENTAGE DISTRIBUTION PATTERN OF *Buliminella elegantissima*

tribution of this species are its tolerance of a some-
what wider range of temperatures and salinity than
deeper-water species, and its preference for a
sandy bottom.

Buliminella elegantissima is a hyaline species known to
live in shallow water. As can be seen in text-fig. 9,
this species is well represented in Santa Monica
Bay, and ranges somewhat deeper than *Trochammina
pacifica*. Its depth of greatest abundance is at
40 fathoms, at a distance of about 1½ miles off Palos
Verdes.

From other studies by the present writer, *Buliminella
elegantissima* is known to live in tidal pools and marine
lagoons, where water temperatures and salinity nor-
mally exhibit extreme changes. In the bay this
species, as can be observed in text-figure 9, tends to
congregate around the mouth of the fresh-water
Ballona Creek. The zone of abundance then trends
southward although moving offshore about 3 miles.
Near Palos Verdes it approaches the shore again.

A few dead specimens were found as deep as 380
fathoms in Redondo Canyon, but the greatest depth
at which a living individual was found is only
60 fathoms. The writer believes that specimens with
a weathered appearance in the canyon are probably
reworked from Pliocene sediments.

Intermediate-depth species

Bulimina denudata, a hyaline species, is the most
abundant species living in the bay. It can be seen
in text-figure 10 that this species reaches its peak,
making up 70 per cent of the foraminiferal assem-
blage, about 2½ miles off Manhattan Beach, at a
depth of 31 fathoms. As can be noted on the dis-
tribution map, this species is very abundant in a
zone at this approximate depth paralleling the coast
in this area. Dead specimens were found between
6½ and 380 fathoms, and living specimens were found
in the bay from 10 to 105 fathoms.

Bulimina denudata lives on all types of sediment occur-
ring in the bay. Temperature and depth seem to be
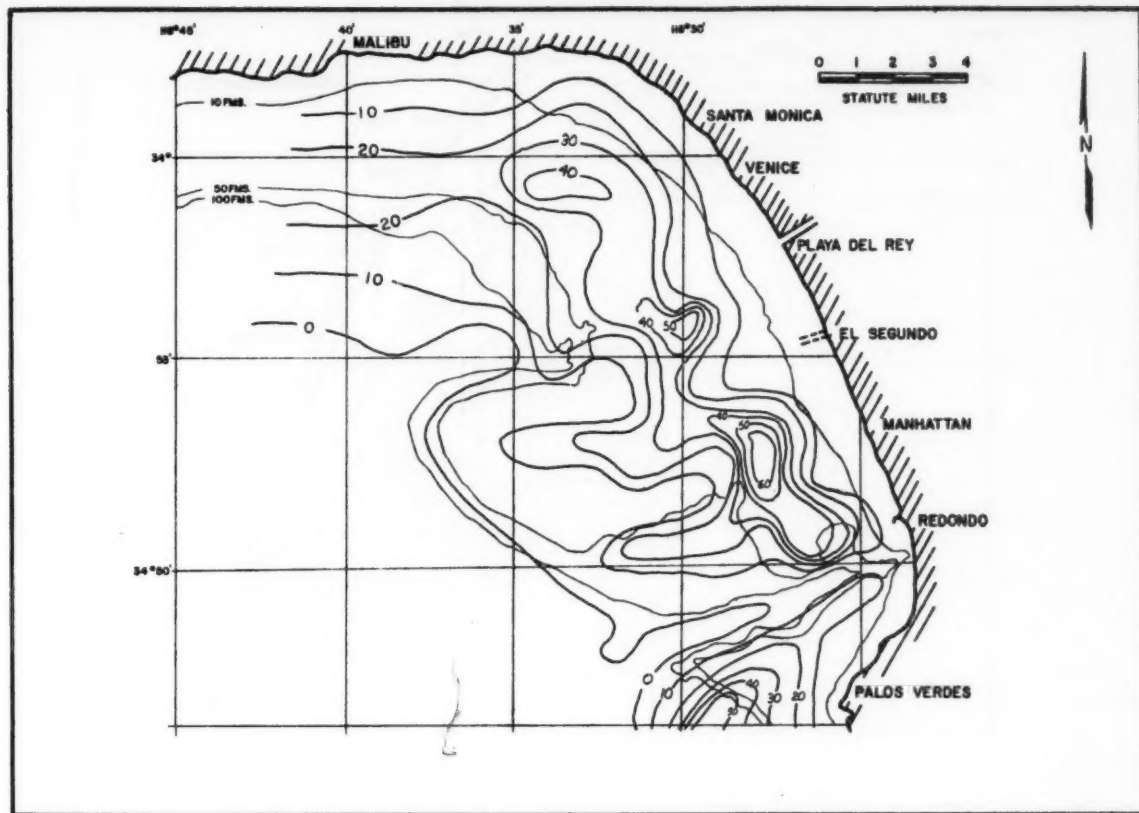
TEXT-FIGURE 10

PERCENTAGE DISTRIBUTION PATTERN OF *Bulimina-denudata*

the main factors controlling the distribution of this prolific species. *Bulimina denudata* is very scarce or absent in extremely shallow water along the shore, in very deep water beyond the shelf, and in the canyons.

Nonionella miocenica stella is a hyaline form with a distribution pattern very similar to that of *Bulimina denudata*, as can be seen in text-figure 11. Its depth of maximum abundance is approximately 27 fathoms, but specimens range from 6½ to 315 fathoms. Living individuals were found as deep as 300 fathoms, but, as is shown on the distribution map, they are very few in number when compared with more abundant deep-water dwellers in these samples.

This species appears to have little or no preference for any sediment type, and as it is widely distributed in the area, it is thought to be restricted primarily by temperature. The large percentage of this species found near shore at the head of Redondo Canyon is of interest. The depth at this point is the same as that of the zones of greatest abundance farther out

on the shelf, which would also seem to indicate that temperature is the most important known factor producing this phenomenon.

Cassidulina californica, Cassidulina limbata, Cassidulina subglobosa, and *Cassidulina tortuosa* were found to have almost identical geographic and bathymetric ranges in Santa Monica Bay. In order to show their distribution, they are plotted collectively in text-figure 12. These species have a rather restricted geographic range on the outer part of the shelf between the two submarine canyons. The area of greatest abundance is at a depth of about 38 fathoms and is located about 6½ miles from shore. Although their depth range is not much greater than that of *Bulimina denudata* and *Nonionella miocenica stella*, these four species of *Cassidulina* are abundant about 3 to 4 miles farther out in the bay.

As the temperature and salinity are so similar in both environments, these factors are probably not the important agents separating these groups of species. It is possible that bottom sediments may be
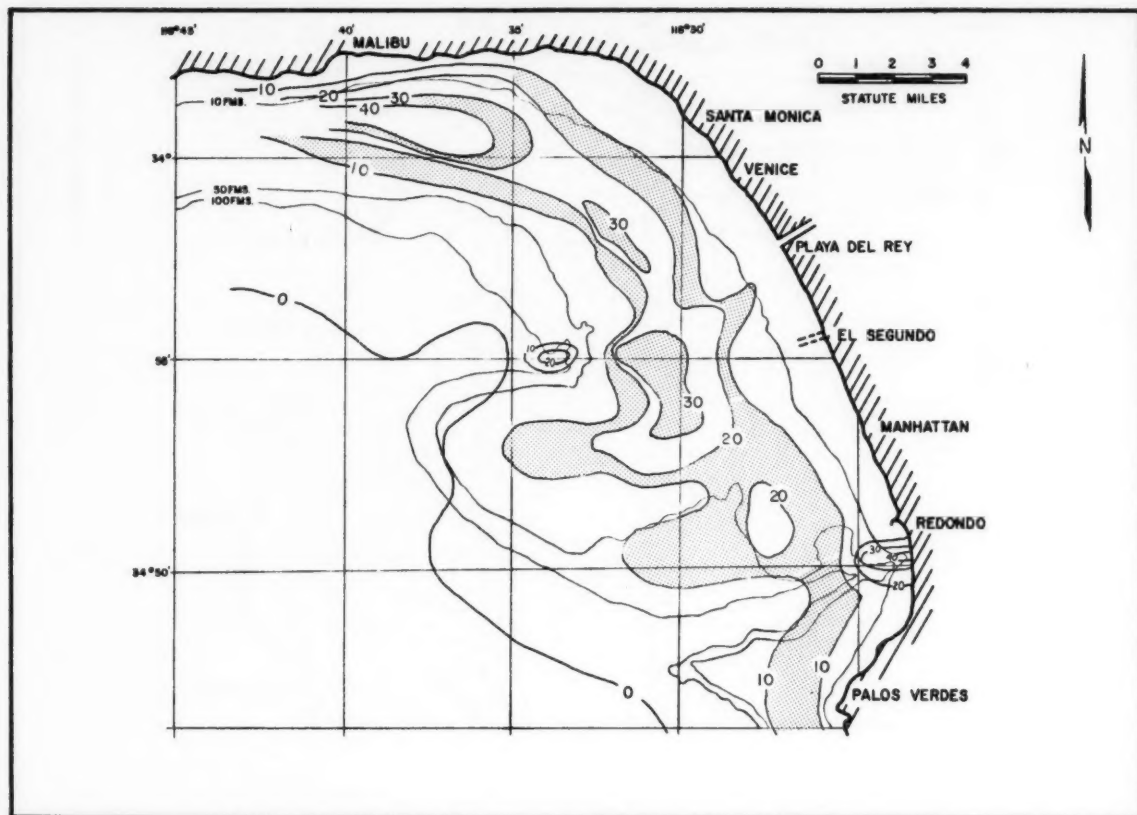
TEXT-FIGURE 11

PERCENTAGE DISTRIBUTION PATTERN OF *Nonionella miocenica stella*

responsible. The sediments upon which the four *Cassidulina* species are living are predominantly rock, gravel, and sand, whereas the other species live primarily on silt and sand. The animals may be especially attracted to these sediment types, or if not, it is possible that their preferred food is found in such places. The fact that the zones of decreasing abundance of the *Cassidulina* species closely parallel depth contour lines, which would indicate that depth, temperature, and perhaps salinity are also restrictive agents, is of interest. Dead specimens range from the shallowest to the deepest samples in the bay; however, no living specimens were found in the stained samples.

Deep-water species

Bolivina argentea monicana is the most abundant species populating the deeper parts of Santa Monica Bay, which includes the two submarine canyons and the area beyond the continental shelf. In text-figure 13, this interesting distribution pattern is very apparent. No specimens of *Bolivina argentea monicana*, either

living or dead, were found on the relatively flat and shallow shelf area, which is so densely covered with other species. Of equal importance is the fact that this species becomes almost entirely absent near the outer margin of the bay at depths approaching 500 fathoms.

The area of greatest abundance of *Bolivina argentea monicana* is in Redondo Canyon at a depth of 280 fathoms, where it makes up 74 per cent of the foraminiferal assemblage. Zones of decreasing abundance extend into shallower and deeper water from this point. Dead individuals were found from 110 to 460 fathoms in the bay, while living specimens had a narrower depth range, from 220 to 300 fathoms. This species is found living exclusively on a silt and clay bottom in the basin and on the slope. Depth and temperature are no doubt the important factors causing the sharply delineated geographic and bathymetric realm of this species.

Bolivinita minuta is a hyaline species living somewhat farther out on the slope than *Bolivina argentea moni-*
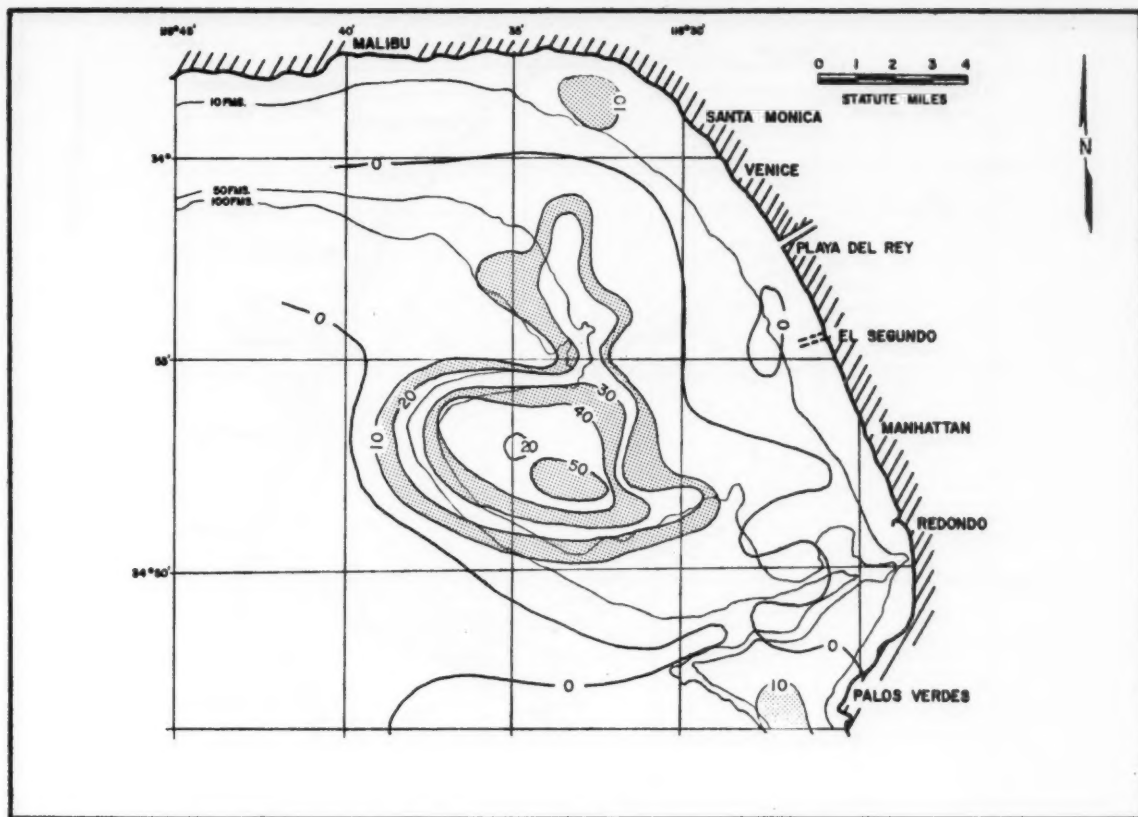
TEXT-FIGURE 12

PERCENTAGE DISTRIBUTION PATTERN OF FOUR SIMILAR SPECIES OF *Cassidulina:*
Cassidulina limbata, C. tortuosa, C. subglobosa, AND *C. californica*

cana, as can be observed in text-figure 14. This species is found primarily beyond the shelf and the canyons. Its depth of greatest abundance is about 270 fathoms, but dead specimens are distributed from 220 to 460 fathoms in the bay. Living specimens were found to range from 370 to 390 fathoms. *Bolivinita minuta* lives on a silty bottom, and the other factors governing the distribution pattern seem to be depth and temperature.

Wide depth-range species

Bolivina pacifica is probably the best example of a euryhaline and eurythermal species living in Santa Monica Bay. As can be seen in text-figure 15, the distribution pattern of this species exhibits no well defined trends like the examples discussed previously. Dead individuals range from 6½ to 380 fathoms in the area, whereas living specimens were collected from 25 to 300 fathoms. Other species with similar characteristics are *Bulimina auriculata* and *Fissurina lucida.*

FREQUENCY DISTRIBUTION PROFILES

Redondo submarine canyon profile

Eleven Hayward-grab samples were taken along the bottom of Redondo Canyon from depths of 36 fathoms to 460 fathoms. The frequency profile (text-fig. 16) illustrates the progressive changes taking place in the foraminiferal assemblages from shallow water at the head down to deep water near the mouth of the canyon. Both living and dead individuals were counted, in order to show the maximum ranges of all species.

As can be seen in the profile, some species make up the greater percentage of the assemblage in shallow water, others reach their greatest abundance in intermediate depths, and still other species dominate the deepest part of the canyon. A few species, usually minority groups, display no particular restriction in depth range in the canyon, and are sparsely represented in nearly all samples. Most of these specimens, however, appear to be weathered, and are
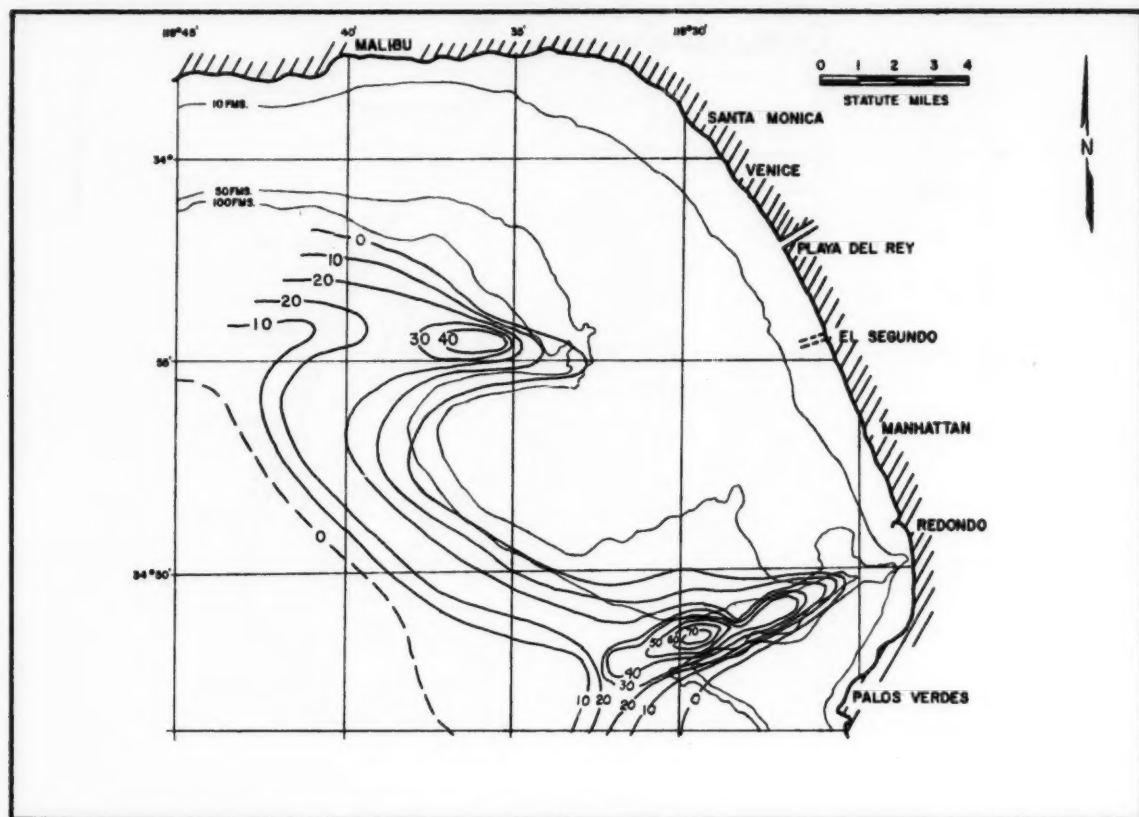
TEXT-FIGURE 13

PERCENTAGE DISTRIBUTION PATTERN OF *Bolivina argentea monicana*

---

probably reworked. Examples of these species are *Buliminella elegantissima*, *Uvigerina juncea*, and *Uvigerina peregrina*.

Important species which were found to be the most abundant in the shallow part of the canyon, from 36 to 100 fathoms, are *Nonionella miocenica stella*, *Buliminella elegantissima*, *Bulimina denudata*, *Nonionella basispinata*, and *Trochammina pacifica*. In this zone the temperature ranges from 8.8 to about 13.4⁰ C., and salinity varies from 34.05 to about 33.50 parts per thousand. There is a great deal of fluctuation of both temperature and salinity in the shallow part of this zone due to changes in insolation and the influx of fresh water.

Species living in the central portion of the canyon, from 100 to 300 fathoms, are *Bolivina argentea monicana*, *Suggrunda eckisi*, *Bulimina auriculata*, and *Goësella flintii*. Environmental factors favorable to these species are a temperature range from 5.6 to 8.8⁰ C., and a salinity range from 34.38 to 34.05 parts per

thousand. Temperature has a much greater range than salinity in this zone, and is thought to exert the greatest amount of influence upon the foraminiferal assemblage. As can be seen in text-figure 16, *Bolivina argentea monicana* makes up more than 50 per cent of the foraminiferal assemblage in this zone.

An almost complete change in the species is encountered at a depth between 300 and 460 fathoms, in the lower end of the canyon. *Cassidulina delicata*, *Epistominella smithi*, *Epistominella pacifica*, *Buliminella tenuata*, *Valvulineria araucana*, and *Bolivinita minuta* become the dominating groups. In this zone the temperature range is from 4.9 to 5.6⁰ C., and the salinity range is from 34.38 to 34.42 parts per thousand. *Cassidulina delicata* dominates the microfauna in this zone.

In order to compare the depth ranges in Redondo Canyon of the living foraminifera only, the stained specimens were counted and plotted in text-figure 17.
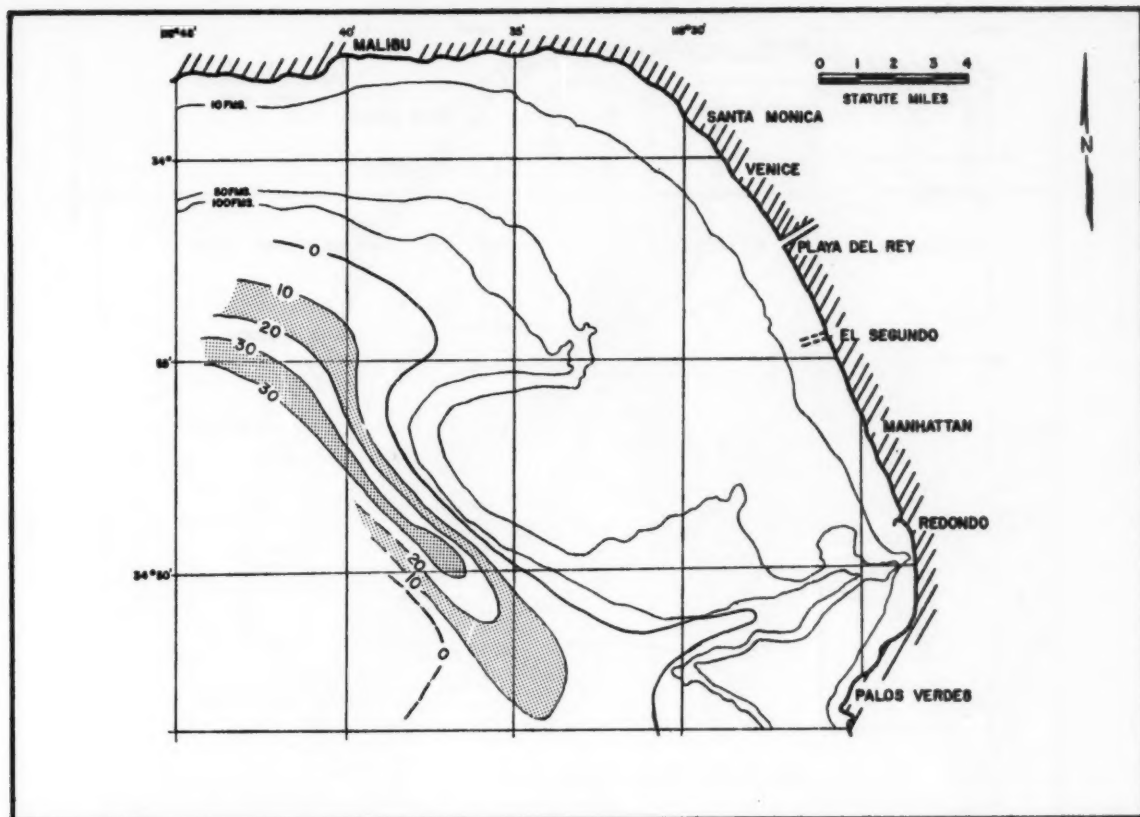
TEXT-FIGURE 14

PERCENTAGE DISTRIBUTION PATTERN OF *Bolivinita minuta*

It was found that living specimens usually made up less than one per cent of the total assemblage in each sample. As would be expected, several of the less abundant species do not appear in the living-specimen profile; however, the species found living were occupying the same depth zones as the dead members of each species. In most instances the depth range of the living was smaller than that of the dead specimens of the same species. Differences between the two profiles are thought to be due to the rather small number of living specimens found in some of the samples.

Shelf profile

Eight samples from a profile beginning near the shore, at the city of El Segundo, and trending seaward across the shelf and down the slope were plotted in a frequency distribution profile, which is shown in text-figure 18. These samples ranged from 17 to 270 fathoms depth, and although the depth zones are not as great as those in the Redondo

Canyon profile, a number of restricted depth ranges are apparent.

In the inner shelf zone, from 17 to 30 fathoms, *Trochammina pacifica*, *Nonionella miocenica stella*, *Buliminella elegantissima*, *Nonionella basispinata*, *Goësella flintii*, and *Proteonina atlantica* are the dominant species. As the temperature in this shallow zone varies from 9.6 to about 13.4° C., it thus becomes apparent that these species are, to some extent, eurythermal. Salinity varies from 33.50 to 33.55 parts per thousand, but fluctuates rapidly within this narrow range.

The outer shelf zone, which is between 30 and 50 fathoms in Santa Monica Bay, is inhabited principally by such species as *Cassidulina californica*, *Cassidulina subglobosa*, *Cassidulina tortuosa*, *Cassidulina limbata*, and *Angulogerina angulosa*. Although the temperature and salinity are slightly different from that of the shallower zone, it is thought that the rock and gravel bottom of the outer shelf may exert the

115
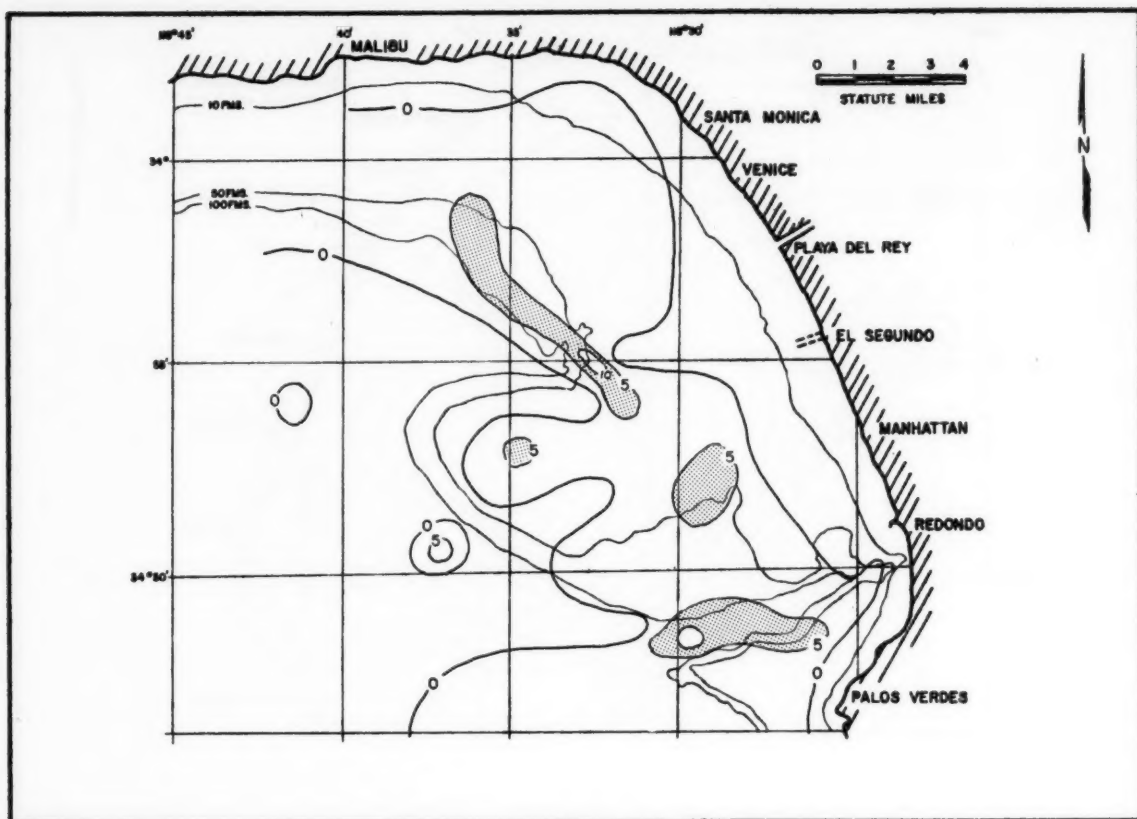
TEXT-FIGURE 15

PERCENTAGE DISTRIBUTION PATTERN OF *Bolivina pacifica*

greatest influence upon the foraminiferal assemblage.

The slope zone, which ranges from a depth of 50 to 270 fathoms, is also characterized by its typical microfauna, featuring *Bolivina argentea monicana*, *Bolivinita minuta*, and *Cassidulina delicata*. These species are the same as those inhabiting the 100- to 300-fathom zone in Redondo Canyon.

Bolivina pacifica, a species known to have a very wide range, was found to live in almost all parts of the bay regardless of depth or bottom-sediment type. The greatest abundance of this species, however, was at a depth of about 45 fathoms.

RANGES OF LIVING AND DEAD SPECIMENS

It was found that the dead individuals of every species occupied a greater depth range than the living specimens. This would, of course, be expected, because the living fraction made up such a small part of the total population in each sample. The ranges of the living and dead specimens of those species found living are plotted and compared in text-figure 19. For easy reference they are arranged according to depth from shallow- to deep-water types, and the line symbolizing a specific depth range thickens on the chart at depths of greatest abundance. Restricted depth zones for many species become very apparent when presented in this manner.

BENTHONIC AND PLANKTONIC SPECIES RELATIONSHIPS

Two profiles were constructed trending from shallow to deep water in Santa Monica Bay. They show interesting percentage relationships between the planktonic or floating species and the benthonic or bottom-dwelling species.

The first profile (text-fig. 20a) runs along the bottom of Redondo Canyon from a depth of 36 fathoms to a depth of 470 fathoms. As can be seen in the profile, the benthonic species increase rather steadily from 53 per cent at the head of the canyon to 85 per cent

DEPTH IN FATHOMS

AHF STATION NOS.
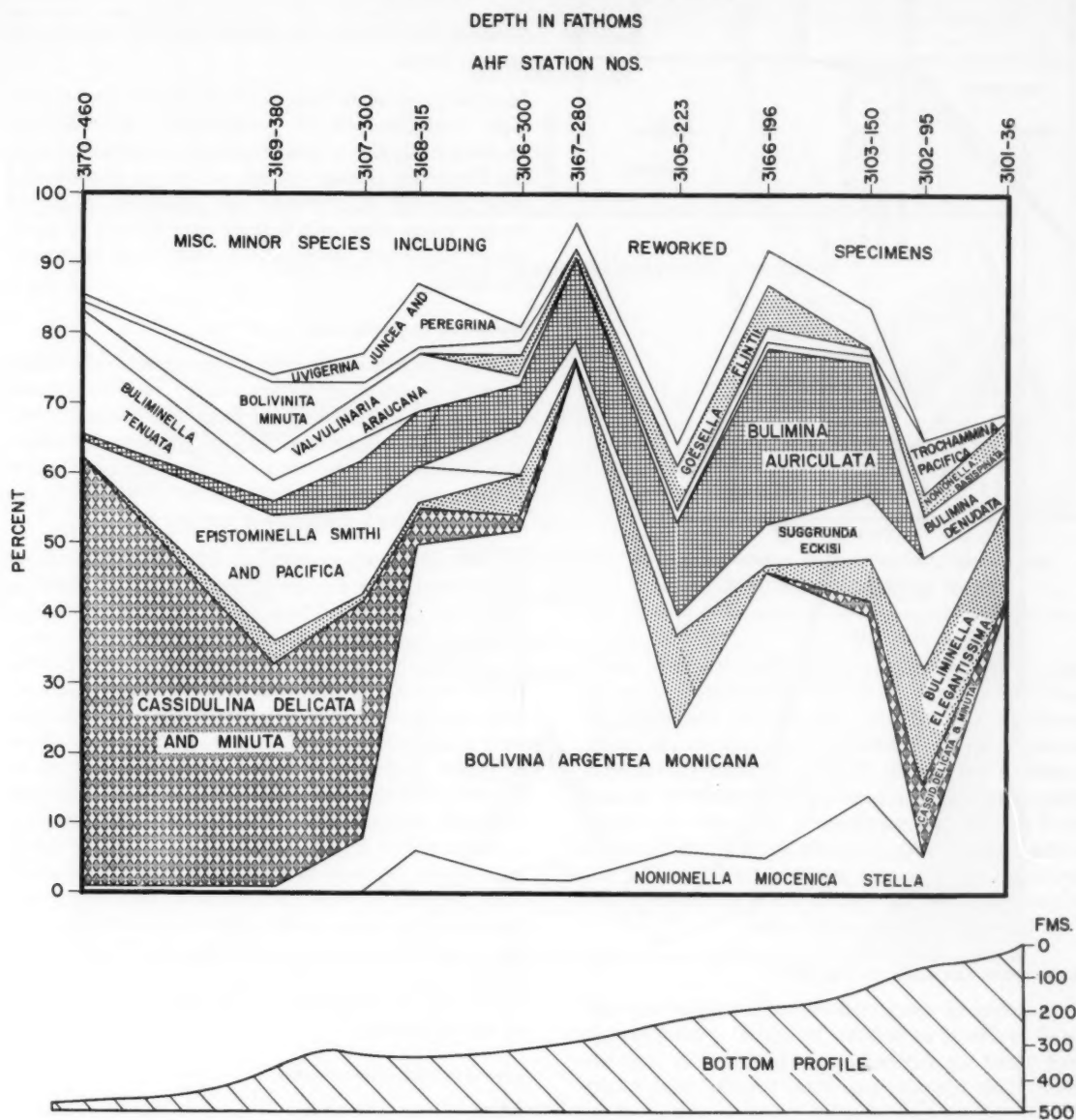
TEXT-FIGURE 16

FREQUENCY DISTRIBUTION PROFILES OF LIVING AND DEAD SPECIMENS
OF ALL FORAMINIFERAL SPECIES IN REDONDO CANYON

at the deepest part. Assuming that the planktonic species are more or less evenly distributed over the surface of the bay, this would indicate that the benthonic species increase in numbers with greater depth in the submarine canyon.

The second profile (text-fig. 20b) runs across the shelf and down the slope. Near the city of El Segundo, this profile starts at a depth of 17 fathoms and trends seaward to a depth of 270 fathoms. As can be seen in the profile, benthonic species provide 98 per cent of the fauna in the shallowest sample, at a depth of 17 fathoms. The percentage of benthonic species as compared to planktonic species then shows a rather steady decrease with depth, until the benthonic types make up only 75 per cent of the assemblage at a depth of 270 fathoms.

DEPTH IN FATHOMS
AHF STATION NOS.

FREQUENCY DISTRIBUTION IN REDONDO CANYON
OF LIVING SPECIMENS ONLY

TEXT-FIGURE 17

Figure labels: BOLIVINITA MINUTA; BULIMINELLA TENUATA; BOLIVINA ARGENTEA; MONICANA; GOËSELLA; BOLIVINA FLINTII; BULIMINA AURICULATA; CASSIDULINA DELICATA; PLANULINA ORNATA; GLOBOBULIMINA PACIFICA; PACIFICA; NONIONELLA MIOCENICA STELLA; BULIMINA DENUDATA; NONIONELLA MIOCENICA STELLA. Y-axis: PERCENT.

distance from shore is no doubt partially responsible for this trend.

In a few parts of the bay, however, zones of unusually high concentration of foraminifera were found. Striking examples of this phenomenon occurred near the Hyperion sewage outfall, where an abnormally large amount of nutrients are available, and also on the outer edge of the shelf near the rocky area, where reworked foraminifera may have increased the fauna.

REWORKED FORAMINIFERA

In many instances, reworked specimens in the Santa Monica Bay samples have a chalky appearance and can easily be differentiated from the Recent specimens. Reworked foraminifera of Miocene, Pliocene, and Pleistocene age were found, and the distribution of these fossil types corresponds rather closely to the locations of rock outcrops of similar age.

Reworked species ranging in age from Pliocene to Pleistocene were found within 2 miles of shore in Redondo Canyon. These fossils, including *Bolivina interjuncta* and *Bolivina subadvena sulphurensis*, occur in Los Angeles Basin Pliocene sediments. Farther out in the bay, along the sides of both submarine canyons and on the surface of the outer shelf near the rock and gravel area, a number of middle and upper Miocene species were found, including *Bolivina decussata*, *Bolivina perrini*, and *Uvigerina hootsi*. Beyond the shelf, several species ranging in age from Pliocene to Recent were found. The most common were *Bolivina sinuata*, *Bulimina dubia*, and *Bulimina subacuminata*. This systematic fossil distribution, indicating that the Miocene rocks on the outer shelf are flanked on the seaward and landward sides by Pliocene outcrops, appears to add support to the fault-block island theory suggested by the distribution pattern of the sediments.

SUMMARY AND CONCLUSIONS

Most of the abundant living foraminiferal species studied exhibit sharply defined geographic and bathymetric ranges. Certain species populate shallow zones along the shore, others prefer deeper water on the outer shelf, and still other types live exclusively in the submarine canyons or beyond the shelf. Important environmental factors causing the restriction of foraminiferal species in the bay appear to be temperature, depth, nutrients, bottom sediments, and, to a somewhat lesser degree, salinity and currents.

Evidence indicating the way in which nutrients influence foraminiferal distribution patterns can be

Upon comparison of the two profiles, it will be noted that in the canyon the benthonic species increase in percentage with depth, whereas on the shelf the benthonic forms behave in the opposite manner, decreasing with depth. It is thought that the surface-current pattern which transports plankton in and out of the bay may influence this ratio by transporting a greater supply of plankton to certain areas than to others. It is also possible, however, that the variation in benthonic species living in certain places in the bay might change this ratio.

FORAMINIFERA PER GRAM OF SEDIMENT

The number of specimens in each sample was estimated as closely as possible by splitting each sample down until an easily countable fraction was obtained. This fraction was then counted and multiplied by the number of splits taken, which gave the total foraminifera in each sample. This total was then divided by the number of grams of processed sediment, which gave the number of foraminifera per gram of sediment in each area sampled, as shown in text-figure 21.

Generally, and with a few exceptions, the number of foraminifera per gram of sediment was found to increase with distance from shore until the deep water beyond the shelf was reached, where a slight decrease became apparent. Along with zones of varied foraminiferal abundance, a steady decrease in the amount of masking detrital material with

DEPTH IN FATHOMS

AHF STATION NOS.

TEXT-FIGURE 18

FREQUENCY DISTRIBUTION PROFILES OF LIVING AND DEAD SPECIMENS
OF FORAMINIFERAL SPECIES ON THE SHELF AND SLOPE
BETWEEN SANTA MONICA CANYON AND REDONDO CANYON

DEPTH IN FATHOMS

TROCHAMMINA PACIFICA
EGGERELLA ADVENA
PROTEONINA ATLANTICA
BULIMINELLA ELEGANTISSIMA
BUCCELLA FRIGIDA
NONIONELLA BASISPINATA
EPISTOMINELLA BRADYANA
BOLIVINA ACUMINATA
BULIMINA DENUDATA
NONIONELLA MIOCENICA STELLA
GOESELLA FLINTII
BOLIVINA PACIFICA
BULIMINA AURICULATA
PLANULINA ORNATA
GLOBOBULIMINA PACIFICA
BOLIVINA ARGENTEA MONICANA
BOLIVINITA MINUTA
CASSIDULINA DELICATA
BULIMINELLA TENUATA

LIVING SPECIMENS
DEAD SPECIMENS

TEXT-FIGURE 19

DEPTH RANGES OF LIVING COMPARED WITH DEAD
SPECIMENS

TEXT-FIGURE 20A

RELATIVE PERCENTAGES OF PLANKTONIC AND BENTHONIC
SPECIES IN REDONDO SUBMARINE CANYON
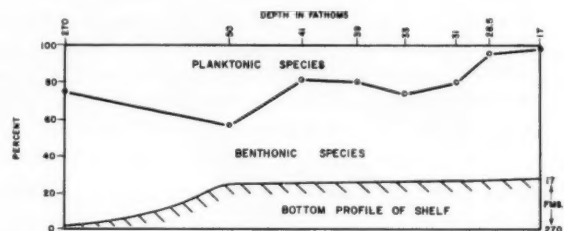
TEXT-FIGURE 20B

RELATIVE PERCENTAGES OF PLANKTONIC AND BENTHONIC
SPECIES ON SHELF BETWEEN SANTA MONICA CANYON AND
REDONDO CANYON

seen best in the study of a typical shallow-water species, *Trochammina pacifica*. This species makes up an overwhelming percentage of the assemblage near the end of the Hyperion sewage outfall, and shows a steady reduction of abundance in all directions from this point.

It is known that temperature decreases with depth, and because so many species were found to be restricted to certain depth zones in the bay, these environmental factors together must exert a great deal of control over most foraminifera. A well developed thermocline caused by the presence of a warm-water layer overlying colder water in Santa Monica Bay causes a sharp drop in temperature at a depth of about 10 fathoms. This probably affects some of the shallow-water species along the beach, but many species living in this zone are extremely eurythermal and may not be restricted by this factor alone.

It seems logical to assume that over a long period of time, certain deep-water species could become adapted to a narrow temperature and salinity range, thus becoming over-specialized and dependent upon these conditions. All through geologic history, this conditioning to a special environment has been known to occur repeatedly among virtually all animal groups.

Bandy (1953) noted a few cases in which identical species occupied zones of somewhat different temperature and salinity ranges in profiles separated by several degrees of latitude along the California coast. Perhaps changes in sea-level and temperature during the Pleistocene could account for this. It is also possible that isolated segments of a species are able to adapt themselves slowly t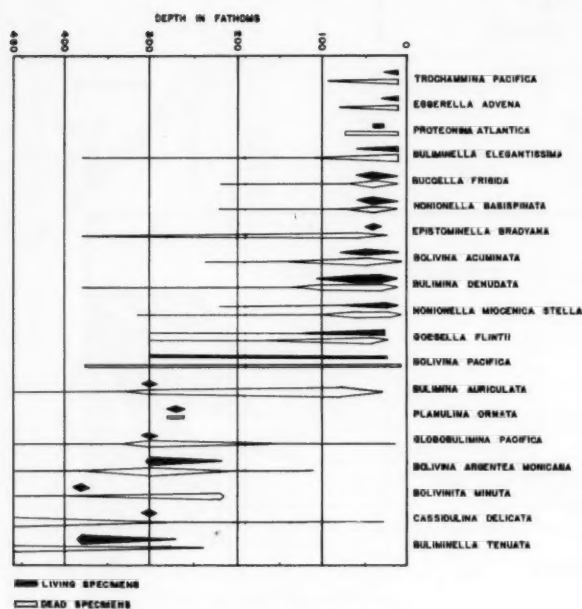o gradually changing conditions, thus making possible the bathymetric migration of an isolated group over a long period of time.

Bottom sediments seem to be the influencing factor affecting the abundance of several species of *Cassidulina* on the rock and gravel area in the bay. It does not seem likely that temperature or salinity alone would hinder their migration into water only a few fathoms shallower, on the inner part of the shelf. The greatest known environmental difference between the two areas is the sediment. The slightly shallower zone has a silty bottom, whereas these species live in great abundance on the gravel and rock.

Surface currents seem to influence the ratio of planktonic to benthonic species in some parts of the bay. The percentage of planktonic species was found to be significantly less in the shallow water along the central shoreline of the bay than in the adjoining shallow-water zones north and south of this area.
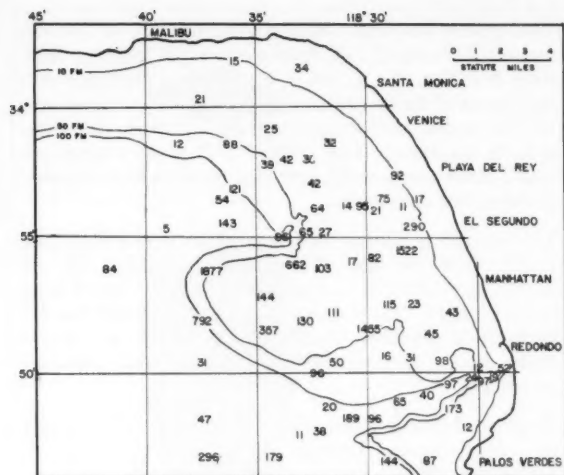
TEXT-FIGURE 21

FORAMINIFERA PER GRAM OF SEDIMENT

This is thought to be due to surface currents entering the central part of the bay, diverging upon nearing shore, and circulating out of both the northern and southern ends of the bay.

From this study it has become apparent that the great majority of foraminiferal species on the sea floor studied are more or less restricted to certain depth zones. The main factor causing this zonation is thought to be temperature, although other environmental factors, such as nutrients and sediment types, definitely affect certain species. Salinity and current movement appear to exert the least amount of influence over the foraminifera in this embayment, probably because these factors do not cause extreme or rapid changes in the marine environment here.

The interesting problems encountered in these ecologic studies of foraminifera in Santa Monica Bay indicate that such studies are a very fertile field for world-wide research. The information gained from similar work in all types of marine environments would have a high segree of practical value in oil exploration, as well as great academic value to persons engaged in research.

DESCRIPTIONS OF NEW SPECIES AND VARIETIES

Family BULIMINIDAE Jones, 1876

Genus BOLIVINA d'Orbigny, 1839

Bolivina argentea Cushman var. monicana
Zalesny, **new variety**
Plate 1, figure 1a–b

Bolivina argentea Cushman. – WALTON, 1955, Jour. Pal., vol. 29, no. 6, p. 1001, pl. 101, figs. 26–27.

Test elongate, slightly twisted, much compressed; edge very acute and keeled, with a short apical spine on most specimens; width increasing slowly after the first few chambers until the adult portion is reached, in which the length is approximately twice the width; sutures oblique and curved; chambers usually eleven pairs, decidedly imbricate; wall finely perforate, smooth except for two or more costae covering the proloculus and extending upward over the first few chambers; color of test light silvery gray; length up to 1.20 mm.; breadth 0.60 mm.

This variety differs from the holotype and from typical examples of the species (see Cushman, 1926, Cushman Lab. Foram. Res., Contr., vol. 2, pt. 2, no. 29, p. 42) in the greater number of chambers, the imbricate chamber arrangement, the greater compression of the test, and the larger size.

Locality: Santa Monica Bay, California, at a depth of 300 fathoms (latitude 33°48′14″ N., longitude 118°30′30″ W.).

Age: Recent.

Holotype: U.S.C. no. 4568.

Family TEXTULARIIDAE d'Orbigny, 1846

Genus TEXTULARIA Defrance, 1824

Textularia conica d'Orbigny var. monicana
Zalesny, **new variety**
Plate 1, figure 2a–b

Textularia conica d'Orbigny. – BANDY, 1953, Jour. Pal., vol. 27, no. 2, pl. 21, fig. 10.

Test broad, subtriangular in outline, suboval in end view, edge rounded; chambers usually five pairs, slightly inflated, increasing in size relatively less with the addition of each new chamber, which gives the test a convex appearance in side view; breadth slightly less than length in adult portion; sutures slightly curved and slightly depressed between first two or three chambers; wall arenaceous, smoothly finished; aperture a low opening in a slight depression at the base of the last septal face; length of holotype 0.8 mm.; width 0.7 mm.; thickness 0.2 mm.

This variety differs from typical *Textularia conica* d'Orbigny (1839, in De la Sagra, Hist. Phys., Pol., Nat. Cuba, Foraminifères, p. 143, pl. 1, figs. 19–20) in having convex instead of concave sides as a result of differential chamber growth.

Locality: Santa Monica Bay, California, at a depth of 33 fathoms (latitude 33°54′07″ N., longitude 118°31′52″ W.).

Age: Recent.

Holotype: U.S.C. no. 4571.

Family NONIONIDAE Reuss, 1860

Genus NONIONELLA Cushman, 1926

Nonionella monicana Zalesny, **new species**
Plate 1, figure 3a–c

Nonionella sp., WALTON, 1955, Jour. Pal., vol. 29, no. 6, pl. 101, figs. 18–20.

Test small, oval, peripheral margin rounded; chambers rather narrow, slightly curved, slightly inflated, usually seven in number, increasing greatly in size after the first three or four chambers; inner end of last-formed chamber with finger-like processes on the ventral side, extending over the previous sutures; sutures oblique, slightly curved and depressed; wall smooth; aperture low, elongate; length of holotype 0.10 mm.; breadth 0.06 mm.; thickness 0.03 mm.

This species differs from *Nonionella miocenica* Cushman var. *stella* Cushman and Moyer (1930, Cushman Lab. Foram. Res., Contr., vol. 6, p. 56, pl. 7, fig. 17a–c) in the smaller size and the more oval appearance of the test.

Locality: Santa Monica Bay, California, at a depth of 33 fathoms (latitude 33°54′07″ N., longitude 118°31′52″ W.).

Age: Recent.

Holotype: U.S.C. no. 4570.

Family ROTALIIDAE Reuss, 1860

Genus DISCORBIS Lamarck, 1804

Discorbis monicana Zalesny, **new species**
Plate 1, figure 4a–c

Discorbis rosacea (d'Orbigny). – CUSHMAN AND VALENTINE, 1930, Stanford Univ., Dept. Geol., Contr., vol. 1, no. 1, pl. 6, fig. 5a–c.

Test convex on dorsal side, flat to moderately concave on ventral side; edge subangular to abruptly rounded; chambers inflated, five in final whorl, enlarging gradually in size as added; dorsal sutures limbate, moderately curved, depressed, tangential to edge; ventral sutures slightly curved, depressed; sutural re-entrants tending to develop in last four or five chambers; aperture an arched opening extending from near the edge into the umbilicus; diameter of holotype 0.38 mm.; thickness 0.20 mm.

This species has been referred to repeatedly as *Discorbis rosacea* (d'Orbigny) (= *Rotalia rosacea* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 273), but comparison of specimens of the present species with the type figure and with a model of d'Orbigny's form indicates that there is little similarity. The type of d'Orbigny's species is much more compressed, and it appears to be a member of the genus *Asterigerina*.

This species is similar to *Tretomphalus myersi* Cushman (1943, Cushman Lab. Foram. Res., Contr., vol. 19, p. 26), but differs in having fewer chambers and a more rounded edge. None of the specimens observed has the large float-chamber that is characteristic of *Tretomphalus* during the summer months when the collecting was done.

Locality: Santa Monica Bay, California, at a depth of 12½ fathoms (latitude 33°47′56″ N., longitude 118°25′12″ W.).

Age: Recent.

Holotype: U.S.C. no. 4569.

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PLATE 1

1 *Bolivina argentea* Cushman var. *monicana* Zalesny, n. var. a, side view; b, end view; × 42.

2 *Textularia conica* d'Orbigny var. *monicana* Zalesny, n. var. a, side view; b, end view; × 63.

3 *Nonionella monicana* Zalesny, n. sp. a, ventral view; b, edge view; c, dorsal view; × 500.

4 *Discorbis monicana* Zalesny, n. sp. a, ventral view; b, edge view; c, dorsal view; × 143.
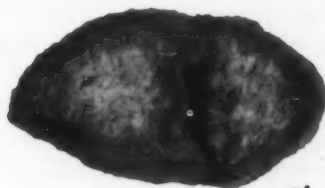
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ABSTRACT: *The first known occurrence of foraminifera in the Upper Carboniferous marine bed near Manendragarh, central India, is reported. Nine species are recorded, including one new species. The fauna is characterized by the exclusive occurrence of arenaceous forms, which show affinity with contemporaneous faunas from the Pennsylvanian of North America.*

Carboniferous (Uralian) foraminifera from Manendragarh, central India

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INTRODUCTION

Until recently, the only known occurrence of marine Paleozoic beds in Peninsular India was that at Umaria, which was discovered by K. P. Sinor in 1921 (*vide* Fermor, 1923). The brachiopod and molluscan fauna was described in detail by Reed (1928), who assigned a Permo-Carboniferous age to the bed. Bhatia and Saxena (1957) reported the first known occurrence of the foraminiferal genus *Hyperammina* (represented by *Hyperammina gracilis* and *Hyperammina* aff. H. *elongata* var. *clavatula*) from this bed.

In a recent publication, Ghosh (1954) reported the occurrence of a small patch of a marine boulder bed at the base of the Talchir series, on the right bank of the River Hasdo, about two and one-half miles northeast of Manendragarh railway station (80° 12 E., 23° 13 N.). The fossil content however, was not described. Datta (1957*a, b*) reported the occurrence of another small patch of a marine boulder bed about one and one-half furlongs upstream from the first outcrop. The fossils recorded by him from this locality are *Eurydesma? cordatum, Eurydesma? globosum, Aviculopecten* sp., and *Pleurotomaria nuda.*

According to Datta (1957*b*, p. 6), the marine bed was deposited in the "shallow waters of a transgressive sea which penetrated into central India (South Rewa) during Uralian time." He further suggested that the "*Eurydesma–Aviculopecten–Pleurotomaria* (*P. nuda*) association favourably, though tentatively, leads to the correlation of the marine boulder bed with the basal part of the lower Speckled Sandstone group, especially of the *Eurydesma* horizon of the Salt Range area." A similar faunal association although not of identical species) has also been reported from the late Carboniferous beds of the Salt Range, Kashmir, Australia, and South Africa.

The discovery of this *Eurydesma* horizon in the heart of Peninsular India is of great paleontological, stratigraphic and paleogeographic significance. It not only extends the limits of the previously known Permo-Carboniferous sea in central India, but it also suggests that the marine transgression commenced during Upper Carboniferous (Uralian) time and continued up to the Lower Permian (Artinskian). It is hoped that further discoveries of a similar nature in other parts of central India will help in deciphering the paleogeography of the area, particularly during the Carboniferous and Permian periods.

The authors have made a paleontological collection from the *Eurydesma* bed near Manendragarh, and the present paper deals with the foraminiferal fauna of this bed. The samples were collected during the 1957–1958 field season. The assistance given by their colleague Mr. K. S. Valdiya is gratefully acknowledged. Thanks are also due to Professor S. R. N. Rao for his kind perusal of the manuscript.

LOCATION OF SAMPLES AND STRATIGRAPHY

In all, five samples (M1–M5) were collected from the marine bed exposed at the base of the Talchir series at the locality first discovered by Ghosh, reference to which was made earlier. The stratigraphic section exposed at this locality is given in Table 1.

COMPOSITION AND AFFINITIES OF THE FAUNA

The foraminifera described in the present paper were obtained from sample M3 (green sandy shale) immediately underlying the boulder bed. Although foraminifera were noted also in the overlying beds, they are too fragmentary to be identified specifically. Their description, therefore, has been omitted from this paper.

TABLE 1

	Sample number	Lithology	Thickness	Fossils
Talchir series	M5	Yellowish-green sandstone	5'-15'	*Aviculopecten* sp., *Spirifer* sp., *Pterinea* sp., small gastropods, and fragmentary foraminifera.
	M4	Boulder bed	2'-2'6''	*Aviculopecten* sp., *Eurydesma* spp., *Pleurotomaria* sp., and fragmentary foraminifera.
	M3	Green sandy shales	6''-9''	No macrofossils, but abundant arenaceous foraminifera.
	M2	Green shale	1'	Unfossiliferous, (?)marine.
	M1	Grey limestone	6''-1'6''	Unfossiliferous, (?)marine.
Archean		Granites and gneisses		

In all, nine species are described and illustrated. These include one new species. A check list is given below.

Hyperammina gracilis Waters
Hyperammina aff. *H. bulbosa* Cushman and Waters
Hyperammina aff. *H. clavatula* (Howchin)
Hyperamina sp. indet.
Glomospira articulosa Plummer
Glomospirella umbilicata (Cushman and Waters)
Lituotuba? sp. indet.
Tolypammina polyverta Ireland
Trochammina hasdoensis Bhatia and Singh, n. sp.

The foraminiferal fauna, which is composed exclusively of arenaceous forms, shows a general similarity to those described from the Pennsylvanian rocks of various localities in North America (Cushman and Waters, 1927*a*, *b*; 1928; Plummer, 1944; Miller and Swineford, 1957). Four species – *Hyperammina gracilis, Glomospira articulosa, Glomospirella umbilicata,* and *Tolypammina polyverta* – have been recorded so far only from Pennsylvanian rocks. The remainder of the species also have affinities with related Pennsylvanian forms.

PALEOECOLOGY OF THE SANDY SHALES
As already remarked, the most notable feature of the fauna from the sandy shales is the occurrence, in great abundance, of arenaceous foraminifera, to the exclusion of all other faunal groups. Although arenaceous foraminifera are known to adapt themselves to a wide range of environmental conditions, varying from shallow, brackish water to typical deep marine waters, the presence of numerous coarsely arenaceous forms in an assemblage is generally indicative of a shallow-water depositional environment. None of the species recorded here, however, occurs in present-day seas.

The most abundant species in the present assemblage is the new species *Trochammina hasdoensis*. Although it presumably does not occur in present-day seas, it shows morphological resemblance (deflated chambers and contorted specimens) to certain Recent species whose ecology is known.

Ronai (1955, p. 140) recorded arenacous forms, consisting of species of the genera *Trochammina* and *Ammoastuta* and finer-grained forms of *Miliammina*, from a warm, turbid, brackish-water environment (11,000–14,000 ppm. chloride ion content). Concerning *Trochammina macrescens* Brady, he noted (*op. cit.*, p. 144) that the deflated tests of this species were similar to the convex tests of other species of *Trochammina*, and that it still remained a problem "as to why certain species of *Trochammina* in a given sample would deflate while others retained their convexity."

This feature was also noted by Parker, Phleger and Peirson (1953, p. 15), who stated that specimens with collapsed chambers occur frequently when specimens are dried. They reported *Trochammina macrescens* and other species of *Trochammina* from brackish-water and near-shore areas in San Antonio Bay. Warren (1957) reported the occurrence of *Trochammina macrescens, T. comprimata, T. inflata,* and *T. lobata from* marshy or brackish-water areas in the Buras Scofield Bayou region, Louisiana. Said (1953, p. 13) recorded a similar *Trochammina* assemblage from the Great Pond Embayment, Falmouth, a sandy to very shallow area subjected to less fluctuation in salinity.

Similarly, Bolin (1956, p. 289) reported *Trochammina minnesotensis* with deflated tests in subsurface Cretaceous sediments from Aitkin and Crow Wing

Counties, Minnesota. On the basis of the evidence furnished by the predominantly arenaceous foraminiferal assemblage and by the nature of the enclosing sediments, Bolin deduced a near-shore, probably cold, brackish-water depositional environment for the assemblage.

A large number of specimens of *Trochammina hasdoensis* show similar morphologic features (i.e., tests with deflated chambers). It is therefore probable that *Trochammina hasdoensis* had the same ecology as *Trochammina macrescens* in the present-day seas and as *Trochammina minnesotensis* during Cretaceous time.

Another peculiar morphologic feature of *Trochammina hasdoensis* is the presence of a number of contorted specimens along with the normal, undeformed tests (see pl. 2, fig. 10a–c). Contortions in foraminiferal tests are generally produced either by variations in salinity or, in the case of attached specimens, by varying modes of attachment.

Arnold (1954), while studying the variation shown by *Discorinopsis aguayoi* (Bermudez) in laboratory cultures, noted that between 10 and 15 per cent of the specimens of that species show noticeable contortion of the test—either along the B-B′ or C-C′ axes (Arnold, *op. cit.*, pl. 2). Although no apparent reason for this contortion was given, it may well have been due to changes in salinity (20 to 57 parts per thousand) to which the living foraminifera were subjected in the laboratory cultures. *Discorinopsis aguayoi* has been recorded from brackish-water areas in San Antonio Bay (Parker, Phleger and Peirson, 1953, where variations in salinity would be marked.

Contorted specimens of *Trochammina hasdoensis*, similar to those of *Discorinopsis aguayoi*, occur frequently in our material. It would perhaps be presumptuous to extend the analogy to *Trochammina hasdoensis*, as the resemblance between the two is purely superficial. The ecologic factor governing the production of contorted tests in *Trochammina* is not definitely known; however, it could well have been compatible with a near-shore, brackish-water environment where changes in salinity are generally marked and frequent. Verification of this hypothesis will have to await detailed studies on the ecology of Recent species of *Trochammina*.

Examination of the data concerning the distribution of other genera, such as *Tolypammina, Hyperammina, Glomospira,* and *Glomospirella*, in present-day seas suggests that they are frequent at depths between 27 and 3800 fathoms see Galloway, 1933). However, Ronai (1955, p. 140) recorded species of *Ammobaculites* and *Hyperammina* and coarse-grained

forms of *Miliammina* in brackish-water environments, in cool, slightly turbid waters of low chloride ion content (1.800 ppm.).

Conkin (1954, p. 167), in discussing the paleoecology of the Floyds Knob formation (Pennsylvanian), concluded that "*Hyperammina kentuckyensis* was an inhabitant of an offshore shallow sea." Miller and Swineford (1957, p. 2028) recorded a foraminiferal assemblage consisting predominantly of arenaceous forms, from the basal 6 inches of Robbins shale (Pennsylvanian) in Douglas County, Texas. The following species were noted by them: *Ammodiscus semiconstrictus, Hyperammina* sp. cf. *H. clavacoidea, Hyperammina* sp. cf. *H. bulbosa, Thurammina* sp. cf. *T. sphaeroidalis, Glomospira articulosa,* and *Reophax* sp. Discussing the paleoecology of these shales, they state (*op. cit.*, p. 2034): "The presence of arenaceous foraminifera (the most abundant faunal element in this zone), a few ostracodes and a few conodonts indicates a near-shore marine or brackish-water environment...." They further report: "No macrofossils, with the exception of a small embryonic shell of a productid (?) brachiopod, were found in this shale. The lack of typical marine invertebrates and the brackish-water aspect of the foraminiferal fauna indicate a near-shore, low-salinity environment of deposition."

The absence of typical marine macrofossils, the presence of an exclusively arenaceous foraminiferal assemblage, and the occurrence of contorted and deflated specimens of *Trochammina hasdoensis* indicate that the sandy shales under consideration were deposited in a near-shore, probably cold, brackish-water environment, with access to the open sea. This is also in accordance with the views of Datta (1957*b*, p. 6), who suggested that this marine bed was deposited in the shallow waters of a transgressive sea.

SYSTEMATIC DESCRIPTIONS

Family HYPERAMMINIDAE

Subfamily HYPERAMMININAE

Genus HYPERAMMINA Brady, 1878, emend.
Conkin, 1954

Hyperammina gracilis Waters
Plate 1, figures 1–2

Hyperammina gracilis WATERS, 1927, Jour. Pal., vol. 1, p. 130, pl. 22, figs. 4–5. – BHATIA AND SAXENA, 1957, Cushman Found. Foram. Res., Contr., vol. 8, pt. 4, pp. 146–147, pl. 21, figs. 5–7.

This species is fairly common in the present material, and the specimens are identical with those described

from the Umaria marine bed by Bhatia and Saxena (1957). The wall appears white, with siliceous cement. This may be due to secondary silicification (see Cummings, 1955, p. 234).

Dimensions: Length up to 1.40 mm.; diameter up to 0.35 mm.

Hyperammina sp. aff. H. bulbosa Cushman and Waters
Plate 1, figure 3

Hyperammina bulbosa CUSHMAN AND WATERS, 1927, Cushman Lab. Foram. Res., Contr., vol. 3, pt. 2, p. 109, pl. 22, fig.7.

A single attached specimen that may be questionably referred to this species occurs in our material. The proloculus is large, globular, and somewhat compressed. This specimen probably represents the megalospheric form of *Hyperammina gracilis.*

Dimensions: Length 0.85 mm.; diameter of the proloculus 0.25 mm.; diameter of the tubular chamber 0.15 mm.

Hyperammina sp. aff. H. clavatula Howchin
Plate 1, figure 4

Hyperammina elongata Brady var. *clavatula* HOWCHIN, 1888, Roy. Micr. Soc. London, Jour., p. 533, pl. 8, figs. 1–2.

Hyperammina clavatula Howchin. – CUMMINGS, 1955, Micropaleontology, vol. 1, no. 3, p. 234.

A few specimens which may be questionably referred to this British Carboniferous species were found in our material. The wall is arenaceous with siliceous cement. It was erroneously referred to as a variety of *Hyperammina elongata* Brady by Bhatia and Saxena (1957). According to Cummings (1955, and personal communication), Howchin's variety should be raised to specific rank.

Dimensions: Length up to 1.75 mm.; diameter up to 0.40 mm.

Hyperammina sp. indet.
Plate 1, figures 5–6

Two fragments, which are illustrated here, apparently belong to this genus, but the absence of a proloculus precludes specific determination. The tubular chamber has numerous irregular depressions over the surface.

Dimensions: Length up to 0.95 mm.; diameter up to 0.30 mm.

Family TOLYPAMMINIDAE
Subfamily INVOLUTININAE

Genus GLOMOSPIRA Rzehak, 1888

Glomospira articulosa Plummer
Plate 1, figures 7–9

Glomospira articulosa PLUMMER, 1944, Texas, Univ., Publ., no. 4401, p. 233, pl. 16, figs. 21–25.

This is a very distinctive species, but it shows considerable range of variation. Its characters were adequately described by Plummer (1944), who noted: "It apparently follows no formal plan of coiling, but twists and turns about itself haphazardly, winding itself into a compact body of no definite shape."

The species was originally described from the Strawn of central Texas. It has also been recorded by Miller and Swineford (1957, p. 2028) from the basal Robbins shale of Texas and by Ireland (1956, p. 847) from the Virgilian series, Upper Pennsylvanian, of Kansas.

Dimensions: Diameter of the tubular chamber up to 0.35 mm.

Genus GLOMOSPIRELLA Plummer, 1944

Glomospirella umbilicata (Cushman and Waters)
Plate 1, figures 10a–c, 11a–b

Glomospira umbilicata CUSHMAN AND WATERS, 1927, Cushman Lab. Foram. Res., Contr., vol. 3, p. 148, pl. 26, figs. 7–8.

PLATE 1

All figures × 42, unless otherwise stated.

1–2 *Hyperammina gracilis* Waters
Lateral views.

3 *Hyperammina* aff. *H. bulbosa* Cushman and Waters
Attached specimen, lateral view.

4 *Hyperammina* aff. *H. clavatula* (Howchin)
Specimen with damaged proloculus; lateral view.

5–6 *Hyperammina* sp. indet.
Lateral views.

7–9 *Glomospira articulosa* Plummer.
Specimens showing varying modes of coiling.

10–11 *Glomospirella umbilicata* (Cushman and Waters)
10, microspheric form, × 54: a–b, opposite sides; c, peripheral view; 11, megalospheric form: a, side view; b, peripheral view.

12–13 *Lituotuba?* sp. indet.
Lateral views.

14–17 *Tolypammina polyverta* Ireland
Top views; lined areas represent the object of attachment.
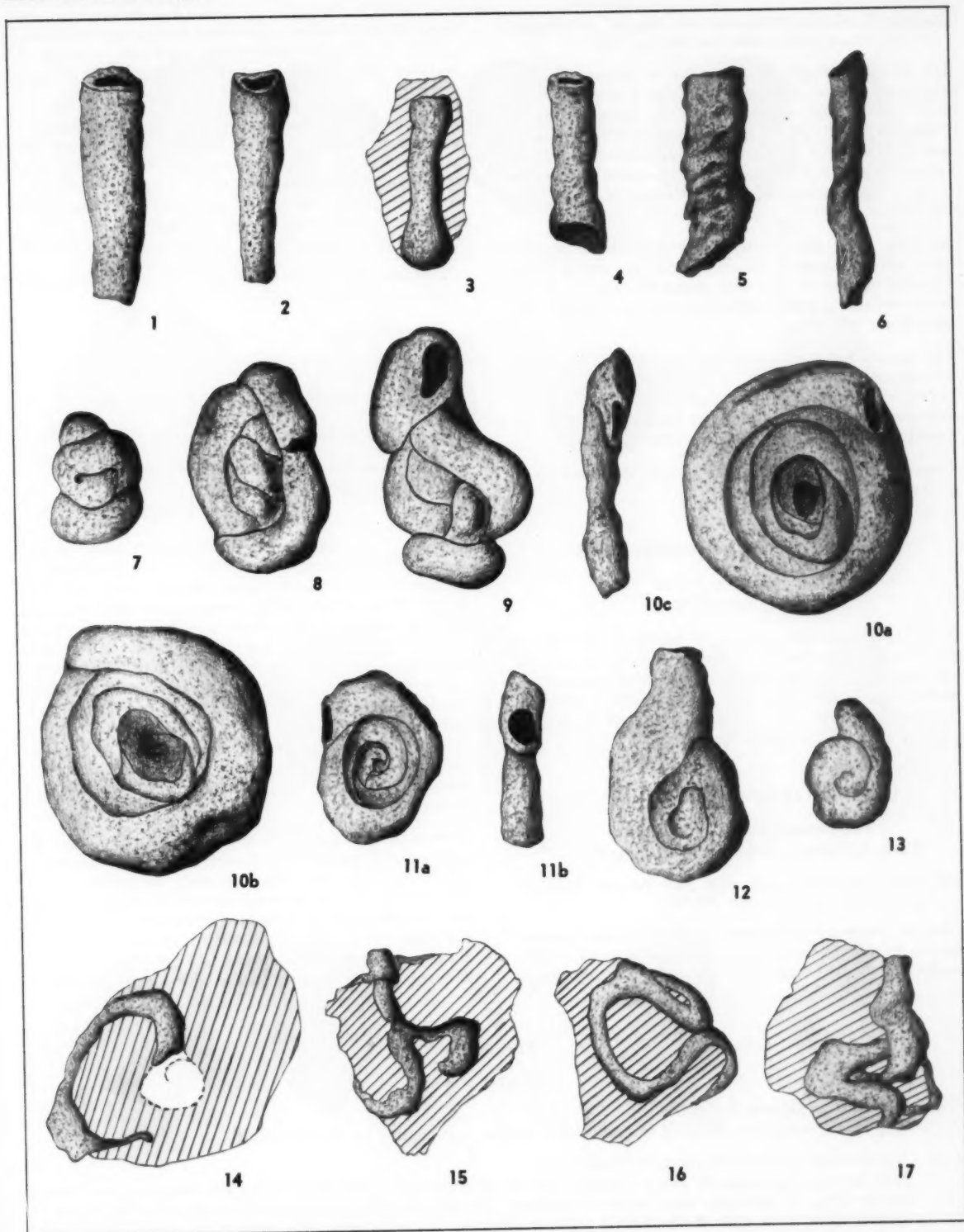
Glomospirella umbilicata (Cushman and Waters). – Plummer, 1944, Texas, Univ., Publ., no. 4401, p. 233.

The species is frequent to common in occurrence. The triangular outline does not seem to be a constant character. This is also apparent from the figures given by Cushman (1948, pl. 42, fig. 25) and by Ireland (1956, text-fig. 4, no. 21), which show specimens with a nearly rounded outline. Our specimens also have a rounded outline, and thus come within the range of variation of the species.

Both the microspheric and the megalospheric generations were recognised. In the former the test is large, rounded in outline, and with about five whorls; in the latter the test is small, somewhat oval in outline, and with fewer whorls.

The species was originally described from the Southwick shale (Pennsylvanian) of Algerita, Texas. Plummer (1944) reported it from the Smithwick, Marble Falls, and lower Strawn beds of central Texas. Ireland (1956) found the species in the Virgilian series of Kansas.

Dimensions: Diameter up to 0.95 mm.; thickness up to 0.15 mm.

Genus Lituotuba Rhumbler, 1895

Lituotuba? sp. indet.
Plate 1, figures 12–13

A few specimens that appear to belong to this genus occur in our material. It is possible that the specimens are variants of *Tolypammina polyverta*, which occurs commonly in the present material. If the object, to which it is attached is small, the tubular chamber covers it completely, and the test appears to be free.

Genus Tolypammina Rhumbler, 1895

Tolypammina polyverta Ireland
Plate 1, figures 14–17; plate 2, figures 1–2

Tolypammina polyverta Ireland, 1956, Jour. Pal., vol. 30, no. 4, pp. 850–851, text-fig. 4, nos. 30–35.

Next to *Trochammina hasdoensis*, this is the most common species in the present material. The specimens are generally attached to large quartz grains. In some speci-mens the test is coiled in the early stages, later increasing rapidly in diameter and coiling randomly in many directions. The wall is finely arenaceous, with siliceous cement.

A few specimens (pl. 2, figs. 1–2) resembling *Glomospira monogranula* Ireland (1956, p. 847) were also found. The authors found it difficult to separate them from typical specimens of *Tolypammina polyverta*, as the only difference between the two is in the size of the objects to which they are attached. The species was originally described from the Virgilian series (Upper Pennsylvanian) of Kansas.

Dimensions: Maximum diameter of the tubular chamber 0.25 mm.; length variable.

Family TROCHAMMINIDAE
Subfamily TROCHAMMININAE

Genus Trochammina Parker and Jones, 1859

Trochammina hasdoensis Bhatia and Singh, new species
Plate 2, figures 3–10

Diagnosis: Test compressed, trochospirally coiled, dorsal side slightly convex, ventral side concave, umbilicate; periphery rounded, somewhat lobulate; two and one-half to three whorls visible on the dorsal side, only the last one visible on the ventral side; five to seven chambers in the final whorl, rapidly increasing in size with growth, the last one being nearly one-third of the size of the test, chambers occasionally collapsed or deflated, resulting in raised margins; sutures rather indistinct, strongly curved on both the dorsal and the ventral side, intersecting the periphery at an acute angle; wall arenaceous, medium to fine grained, with insoluble cement; aperture indistinct, probably at the base of the last chamber.

Dimorphism and variation: Both the megalospheric and the microspheric generations were recognised. In the former (pl. 2, figs. 3–6), the test is strongly compressed, with two and one-half to three whorls on the dorsal side. The last chamber is about one-third of the size of the test. In the latter (pl. 2, figs. 8–9), the test is somewhat inflated, and the last chamber is nearly half the size of the test. The sutures are strongly curved and arched backward.

PLATE 2

All figures × 42.

1–2 *Tolypammina polyverta* Ireland
Top views; specimens attached to small quartz grains, represented by lined areas.

3–10 *Trochammina hasdoensis* Bhatia and Singh, n. sp.
3, Holotype, megalospheric form: a, dorsal view; b, ventral view; c, peripheral view; 4–6, megalospheric forms, dorsal views; 7, specimen with deflated chambers, dorsal view; 8–9, microspheric forms: a, dorsal view; b, ventral view; c, peripheral view; 10, contorted specimen: a, dorsal view; b, ventral view; c, peripheral view.
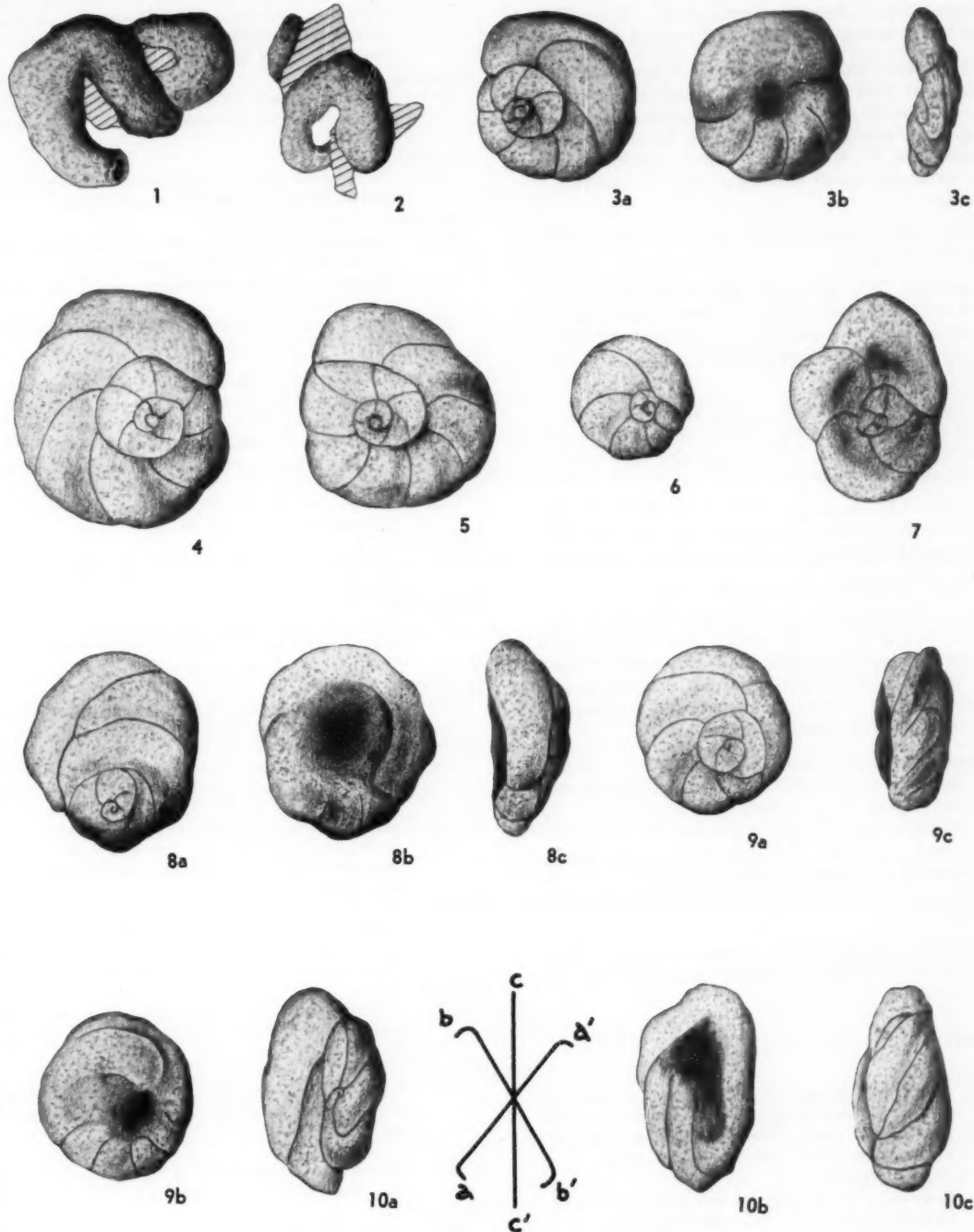
A few contorted specimens (pl. 2, fig. 10a–c) were also noticed, the contortion being along the B–B′ and A–A′ axes (according to Arnold's terminology, 1954). They appear to be ecological variants of normal specimens.

Another notable feature of the species is the presence of a number of tests with deflated chambers (see pl. 2, fig. 7). As already pointed out, this feature is also common in other species of *Trochammina*, for example, *T. macrescens* and *T. minnesotensis*. These specimens also appear to be ecological variants of typical members of the species.

Dimensions: Maximum diameter up to 1.05 mm.; thickness up to 0.28 mm.

Type material: The specimen illustrated in plate 2, figure 3, is the holotype. It is our intention to deposit the holotype and a few paratypes in the paleontological collection of the Geological Survey of India, Calcutta, at a later date.

Type horizon: Bed no. M3, green sandy shale 6 to 9 inches in thickness, underlying the boulder bed containing *Eurydesma* sp., *Aviculopecten* sp., *Pleurotomaria nuda*, and other macrofossils.

Type locality: On the right bank of the River Hasdo, below the railway bridge, about two and one-half miles northeast of Manendragarh railway station.

Age: Upper Carboniferous, Uralian.

Discussion: The species is very distinctive but shows considerable variation, as noted above. It is characterized by having: a) a low trochoid spire; b) five to seven chambers in the final whorl, which rapidly increase in size with growth; and c) strongly curved and backwardly arched sutures, both dorsally and ventrally.

The species somewhat resembles *Trochammina squamiformis* Cushman and McCulloch, from off Milwaukee Pier, Port Angeles, Washington, but differs from it in having strongly curved sutures and in the large, distinctive final chamber. The contorted specimens resemble those of *Trochammina constricta* Haeusler, from the Upper Jurassic of Switzerland, but the resemblance is superficial.

Remarks: The specific name is derived from the River Hasdo, on the right bank of which the marine bed was first discovered.

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Good news!

We are pleased to announce two new policies that will benefit our authors and subscribers. One of these relates to reprints, the other to the payment of subscriptions.

During the early years of the quarterly, financial stringencies were so great that free reprints could not be given to authors. Although we deplored this situation, there was little that could be done about it. Now that our finances are in better condition, however, we are prepared to give our authors 100 reprints free of cost. It will still be necessary to make a charge for copies in excess of that number.

Many of our foreign subscribers have been plagued by the difficulty involved in paying for their subscriptions in dollars. In order to relieve this situation, we are now prepared to accept payment in the currency of the subscriber's country at the prevailing rate of exchange. It will be necessary for us to charge a collecting fee of 5 per cent of the subscription price.

THE EDITORS

news reports

ESTEBAN BOLTOVSKOY

Nearly two years have passed since my last report. In the present one, I have included an account of micropaleontological activities not only in the Argentine but also in Uruguay, as well as whatever news I could obtain from Chile.

First of all I must report the very sad news that on June 22, 1958, Professor Joaquín Frenguelli, the diatom specialist, died at Santa Fe, Argentina. His death is an irreparable loss to Argentine micropaleontologists. A detailed account of his life and work will appear in an early issue of MICROPALEONTOLOGY.

Foraminifera

No papers on fossil foraminifera have been published in Argentina during the past two years, but early in 1958 Dr. H. H. Camacho, who was awarded a J. S. Guggenheim Memorial Foundation Fellowship, left Buenos Aires for the United States, taking with him a collection of Cretaceous foraminifera from the southern part of the Argentine, in order to study them at the U. S. National Museum in Washington. We have learned that this study has been successfully completed, and that the results obtained are interesting and valuable.

Dr. Camacho also published a paper entitled "Nociones de micropaleontología" (Holmbergia, vol. 5, no. 10, 1956), in which the chief aims and methods of micropaleontology were discussed. A brief review of micropaleontological investigations in Argentina was included, as well as a selected bibliography. This paper was intended for the use of University students.

During the past two years, your correspondent published the following five papers on Recent foraminifera: "Cyclical occurrence of foraminifera" (Dusenia, vol. 7, no. 4, 1956); "Las anormalidades en las caparazones de foraminíferos y el 'indice de regeneramiento'" (Ameghiniana, vol. 1, no. 1–2, 1957); "Los foraminíferos del estuario del Rio de la Plata y su zona de influencia" (Rev. Inst. Nac. Invest. Cienc. Nat., Geol., vol. 6, no. 1, 1957); "The foraminiferal fauna of the Rio de la Plata and its relation to the Caribbean area" (Contr. Cushman Found. Foram. Res., vol. 9, pt. 1, 1958), and "Problems in taxonomy and nomenclature exemplified by *Nonion affine* (Reuss)" (Micropaleontology, vol. 4, no. 2, 1958).

In addition, your correspondent published a multilingual dictionary of terms relating to the foraminifera, which contains more than 2000 English terms and their equivalents in four other languages: Spanish, German, French and Russian. The terms are also cross-indexed in the languages mentioned. This dictionary was published by the Departamento de Oceanografía, Servicio de Hidrografía Naval, Ministerio de Marina.

In connection with the International Geophysical Year, the above-mentioned Department engaged several specialists in various branches of physical and biological oceanography. Among them, your correspondent was in charge of the study of some problems relating to the Recent foraminifera of the Argentine shelf and adjacent areas. Although the International Geophysical Year will end in December, 1958, there is still some possibility that the laboratory will continue its work, as the planned study of the ocean and its inhabitants is a very important economic and scientific problem in the Argentine.

Your correspondent is now working on two projects. The first is a study of the south Brazilian foraminiferal fauna and its comparison with that of the Argentine and the West Indies. This investigation was begun near the end of 1956. In the same year your correspondent was awarded a J. S. Guggenheim Memorial Foundation Fellowship, and thus visited the United States for six months during 1957. Some work was carried out in the most important micropaleontological laboratories, and knowledge of many others was obtained. I wish to take advantage of this opportunity to thank my colleagues in the United States again for the warm reception, constant helpfulness, and hospitality shown me during my stay in that country, especially the following: Zach Arnold, Brooks F. Ellis, Don L. Frizzell, Stuart A. Levinson, Alfred R. Loeblich, Angelina R. Messina, Frances L. Parker, Fred B Phleger, W. R. Riedel, Helen Tappan Loeblich, Ruth Todd, and M. Trapesonian.

The second study in which your correspondent is engaged is the determination of the Malvin Current (Falkland Island Current) as indicated by foraminifera. The beginning of this investigation was recorded in my last report. This is a broad project, involving the study

of numerous samples gathered from a very wide area. It is believed that the first part of this study will be completed during 1959.

Thecamoebina

A short paper entitled "Contribución al conocimiento de las tecamebas del Río de la Plata" (Acta Geol. Lilloana, vol. 1) was published by your correspondent in 1956.

Ostracoda

Dr. Camacho also took with him to the United States a collection of fossil Ostracoda, which he intends to study at Louisiana State University, Baton Rouge.

Diatoms

The last studies of the late Dr. J. Frenguelli, which were carried out in collaboration with Dr. H. Orlando (Universidad de Bahía Blanca), were: "Las diatomeas y silicoflagelados del sector Antártico Sudamericano," and "Las diatomeas y silicoflagelados del VI crucero de la operación 'Merluza' (Mar Epicontinental Argentino)." The first paper is now in press (Publicación no. 5, Instituto Antártico Argentino, 1958). Dr. Orlando is at present working to prepare the second one for publication.

In addition, Dr. Orlando is occupied with the study of other diatom material from the Antarctic and South Atlantic areas. Some new species have been discovered, and many others, not previously recorded from these regions, have been found. We hope that some of these investigations will be ready for publication in the near future.

Dr. F. C. Müller-Melchers (Museo de Ciencias Naturales, Montevideo, Uruguay) has published an interesting paper entitled "Las diatomeas del plancton marino de las costas del Brasil" (Univ. Sao Paulo, vol. 6, fasc. 1–2, 1955). Another paper by the same author, on the diatoms of the Argentine and Uruguayan coasts, is now in press. In addition, Dr. Müller-Melchers is occupied with a study of planktonic diatoms from off Cuba, but this investigation is only in the "em-

bryonic" stage, according to his own report.

Dr. H. Etcheverry Daza (Estación de Biología Marina, Universidad de Chile, Viña del Mar, Chile) has for some years been carrying on research on the phytoplankton, especially the diatoms, of the area around Montemar, Chile. He is now preparing a paper on this subject.

Spores and pollen

In recent years an increasing interest in this subject has been shown in the Argentine. Dr. S. M. Archangelsky (Universidad de Tucumán) published a paper entitled "Palinología, una rama de la biología y paleontología" (Ciencia e Investigaciones, vol. 12, no. 9, 1956), in which the aims, methods, and economic applications of palynology were discussed. The purpose of this paper was to call the attention of Argentine botanists to this new branch of the natural sciences, as applied to geology and paleontology. Dr. Archangelsky has also translated the well-known work of Erdtman, "On spore morphology and its terminology," into Spanish. This translation is now in press.

Dr. C. A. Menéndez (Dirección de Minas, Buenos Aires) has published an article on a Jurassic florule from the Province of Neuquén in the Argentine (Acta Geol. Lilloana, vol. 1, 1957). Besides morphological descriptions of the plants encountered, some interesting data on the spores and pollen were also given.

Dr. Gabriela G. Hässel de Menéndez (Museo de Ciencias Naturales, Buenos Aires) is now engaged in a taxonomic study of the Marchantiales and Anthocerotales (Hepaticae) of the Argentine. This investigation deals with about forty species, and will be profusely illustrated, especially the American forms. The genera *Riccia* and *Asterella* are especially interesting because of the unusual ornamentation of their spores. This is well shown in the accompanying plates.

A paper by the same author, entitled "*Monoclea forsteri* en Argentina," was published recently (Bol. Soc.

Argent. Bot., vol. 6, no. 3–4, 1957). Two other papers, on *Riccia* and on the Marchantiales and their spores, are now in press. These three studies are closely related to the author's current work, mentioned above.

In 1957, Dr. F. Vervoorst (Instituto de Botanica, Castelar, Buenos Aires Province) returned to the Argentine from Germany, where he studied palynology under the direction of Professor F. Firbas. After his return to Argentina, Dr. Vervoorst began a systematic study of phanerogam spores as a basis for future investigations of peat and Tertiary coal. This work now is still going on.

Plankton

Dr. R. A. Ringuelet (Universidad de Buenos Aires) has been investigating the fresh-water plankton of Argentina. A paper concerning the chemical factors that determine the distribution of copepods in the fresh waters of Argentina is now in press (Physis, vol. 21, no. 60). In addition, Dr. Ringuelet has prepared an interesting systematic synopsis of the copepods, as well as a paper entitled "Conclusiones biogeográficas sobra copépodos no marinos de la Argentina." The latter paper is now in press (Holmbergia, vol. 6).

Dr. Parmenio Yañez Andrade (Estación de Biología Marina, Universidad de Chile, Viña del Mar, Chile) is studying general problems relating to plankton in the area adjacent to the station. Dr. B. F. Osorio-Tafall, technical assistant to the Consejo de las Naciones Unidas (Santiago, Chile), has carried out an interesting study of some planktonic organisms (Tintinnoinea, Silicoflagellata, Dinoflagellata and others) from the South Pacific waters of Latin America from Mexico to the Chilean Antarctic. Unfortunately, being extremely busy as the resident representative of the above-mentioned organization, he has not yet had sufficient time to write a report on this study.

Other news

As our country is situated somewhat far from the great international routes, in a corner of the world, many visitors cannot be expected here. We have had only two from our

micropaleontological clan, Dr. W. R. Riedel, of the Scripps Institution, La Jolla, California, and Dr. S. Petri, of the Universidad de Sao Paulo, Brazil. Dr. Riedel worked for some time as a specialist on Radiolaria aboard the Argentine icebreaker "Gral. San Martin" in the Antarctic. Dr. Petri visited Buenos Aires for a short time as a tourist. We very much enjoyed the presence of both of them in Argentina.

ESTEBAN BOLTOVSKOY
Museo Argentino de Ciencias Naturales
Buenos Aires

INDIA

YEDATORE NAGAPPA

Professor S. R. N. Rao, who has been your correspondent for the past several years, has resigned for reasons of health. The undersigned has been asked to take over that function.

Geological Society of India

In response to a growing feeling among the senior geologists of this country that a geological society was needed to promote advanced studies and research in all branches of geology, the Geological Society of India was constituted in June, 1958, with headquarters in Bangalore. D. N. Wadia, Geological Adviser, Deparment of Atomic Energy, Government of India, is the first president.

Geological Survey of India

M. R. Sahni, who was Palaeontologist to the Survey, has retired and is now head of the newly established Department of Geology in the University of Punjab, Chandigarh, Punjab, India. Sahni and V. V. Sastri have published a monograph on *Orbitolina* in India and adjacent regions (Pal. Indica, new ser., vol. 33, Mem. 3). Much of the material is from old collections. Seventeen species and subspecies were described, including nine new forms, as well as one new genus, *Birbalina*.

Oil and Natural Gas Commission
Central Laboratories, Dehra Dun

Professor Nina N. Subbotina and Mrs. Paula S. Lubimova, micropaleontologists with the Leningrad Oil Institute, left for the U.S.S.R. toward the end of December, 1957, after a nine-month stay in Dehra Dun. They helped in the organization of the micropaleontological laboratory and in the training of personnel. Mrs. Natilia D. Mtchedlishvilli, a palynologist with the same Institute, spent seven months in Dehra Dun giving training in applied palynology. She left India for the U.S.S.R. in November, 1957.

The palynology section started functioning in November, 1956. Samples from the Siwaliks of Jawalamukhi, Bahl, Nurpur, and Dharamsala have yielded microfloras that make it possible to distinguish Lower, Middle and Upper Siwaliks. Microfloras from the Eocene of Kutch are represented by the pteridophyte families Polypodiaceae, Parkeriaceae, and Hymenophyllaceae, and the angiosperm families Dipterocarpaceae, Nothofagaceae, Euphorbiaceae, Palmae, and others. Slides of extant spores and pollen for comparison with fossil forms are being prepared. Slides are also being exposed to the atmosphere in order to check diurnal and seasonal contamination.

At the 45th Indian Science Congress, held at Madras in January, 1958, A. K. Ghosh and Y. K. Mathur read a paper entitled "Palynological studies on salt, shale and coal from Mandi, and the age of coal beds." Dr. and Mrs. Gunnar Erdtman, of Sweden, visited the laboratory.

A. K. Dutta, R. B. Mehrotra, D. K. Guha, B. N. Srivastava, Madan Mohan, and S. K. Singh received training in paleontology from the Russian experts. S. N. Singh, who returned from the United States in October, 1957, is in charge of the laboratory.

A study of Tertiary fossils from Surat, Broach, Kathiawar, Kutch, and Rajasthan is in progress. The following papers have been released for publication: "Foraminifera from Upper Jurassic deposits of Rajasthan and Kutch, India," by N. N. Subbotina, A. K. Dutta and B. N. Srivastava; "Ostracoda of the Jurassic and Tertiary deposits of Kutch and Rajasthan (Jaisalmer)," by P. S. Liubimova, D.K.Guha, and Madam Mohan; and "Two aberrant types of Nummulitidae from the Eocene of Rajasthan, India," by S. N. Singh.

University of Lucknow

Following the retirement of Professor S. R. N. Rao, R. C. Misra became the new head of the Department of Geology. Misra has prepared a paper on *Fermoria* from the Suket shale (Vindhyan, pre-Cambrian?), in which he suggests that these discoidal bodies are probably non-organic. B. S. Tiwari has reported the occurrence of the arenaceous foraminifera *Trochammina*, *Hyperammina*, *Ammobaculites*, *Bathysiphon*, and *Haplophragmoides* in Permian marine beds near Manendragarh, Madhya Pradesh. His work on the Tertiary foraminifera of Kutch is continuing. S. B. Bhatia and Krishna Mohan have a paper in press on "Miocene (Burdigalian) foraminifera from Kathiawar, western India," in which they have described sixty-five species and subspecies, including one new species. According to them, the fauna has greater affinities with the Indo-Pacific province than with the European basins. Bhatia and S. K. Singh have also written a paper on Permian arenaceous foraminifera from Manendragarh, Madhya Pradesh.

Other investigations in progress by members of the Geology Department include a study of Lower Gondwana microfloras from Birsingpur, by K. P. Vimal; one on Eocene smaller foraminifera from the Surat-Broach

area, western India, by S. K. Singh; and studies on small foraminifera from the agate conglomerates (Miocene) of Gogha, Kathiawar, and from the Jurassic beds of Jaisalmer, by Girjesh Chandra.

A. R. Rao, of the Department of Botany, has published a report on microfossils from the Paleocene Deccan intertrappean beds (The Palaeobotanist, vol. 6, no. 1). He has recorded the occurrence of *Azolla intertrappea* Sahni and Rao, and an interesting new fossil dicotyledonous root, *Dicotylirhizos sahnii* Rao, n. gen., n. sp. The lignites of Palana (Lower Eocene) and Warkalli (Miocene) have yielded on maceration a number of algal remains, fungal spores, and fruit bodies referable to the Microthyriaceae.

Calcutta University

Professor N. N. Chatterji and his colleagues in the Geology Department have published a number of papers on plant microfossils from some of the Gondwana coal measures. Chatterji and D. Chandra have reported on fungal remains of Permian age from the Barakar coal measures of the Kurasia coal field, Madhya Pradesh. They record *Crenasclerotes stachii* Pick., *Cellulasclerotes abnormis* Stach and Pick., *Globosasclerotes agiranus* Stach and Pick., commonly found in European coals of Westphalian age, and *Coronasclerotes australis* Stach and Pick., known from the "Creta" seam of the lower coal measures of Australia and from the Westphalian coal measures of Germany.

In a recent paper (Quart. Jour. Geol. Min. Met. Soc. India, vol. 29, no. 1), D. Bhattacharyya, T. Raychaudhury, and K. Datta have reported six genera of previously described spores. A. Datta (Quart. Jour. Geol. Min. Met. Soc. India, vol. 29, no. 1) has reported on spores from the Lower Gondwana coal measures of Jhagrakhand, Madhya Pradesh. From the Talchirs of this area he has recorded *Florinites* sp., *Laevigatosporites* sp., and *Granulatisporites* sp. K. Sarma (now lecturer in Gauhati University, Assam) has described some small foraminifera from the

Baripada beds (Upper Tertiaries) of Mayurbhanj, Orissa (Quart. Jour. Geol. Min. Met. Soc. India, vol. 28, no. 4).

Standard-Vacuum Oil Company, Calcutta

Microlithology, foraminifera, and spores and pollen from subsurface sections penetrated by three wildcat wells, Burdwan X-1, Galsi X-1, and Jalangi X-1, drilled under the Inso-Stanvac Petroleum Project, are being studied. Formation breakdown and time-correlation of 25,000 feet of section in these wells are under way.

A paper entitled "Stratigraphy of the Mahadeo, Langpar, Cherra and Tura formations, Assam, India," by B. Biswas, was released in 1957 for publication in the Wadia Volume of Journal of the Palaeontological Society of India. In this paper, the status of the respective formations was reviewed from the point of view of the recommendations of the Committee on Rock-Stratigraphic Nomenclature of the American Commission on Stratigraphic Nomenclature. Large and small foraminifera, as well as spores and pollen, were described and illustrated from these Upper Cretaceous, Paleocene, Lower Eocene, and Middle Eocene formations. The Upper Cretaceous to Eocene ranges of many dicotyledonous families known in the form of fossil leaves from the Gulf Coast region of the United States and elsewhere were confirmed by the fossil pollen encountered in these rocks. The Eocene occurrence of some dicotyledonous families, previously unknown, was reported on the basis of pollen evidence. Palynological evidence was cited to support the Lower(?) to Middle Eocene age of the Tura formation. It was inferred that the Cherra formation is developed locally in the Cherrapunji Plateau, and that it is unrepresented in the southern scarp of the Shillong Front.

Assam Oil Company Limited, Digboi

In the Palaeontological Laboratory, the study of the fossils of the Cretaceous – Eocene succession in central Assam is nearing completion. Among the rich and varied microfaunas occurring in these rocks are some

interesting Ostracoda from the Kopili stage (Upper Eocene) belonging to the genera *Cytherella, Cytherelloidea, Paracypris, Krithe, Cythereis, Cytheropteron, Monoceratina, Xestoleberis, Schizocythere,* and *Paijenborchella.*

Bangalore University

L. Rama Rao is continuing his study of the Cretaceous foraminifera of southern India. In a paper dealing with some orbitoids from that area (Proc. Indian Acad. Sci., Sec. B, vol. 45, no. 6), he has recorded the presence of *Lepidorbitoides minor* Thiadens. On the basis of his studies, Rao is inclined to believe that *Orbitocyclina* Vaughan is a valid genus.

YEDATORE NAGAPPA
Assam Oil Company Limited
Digboi, Assam

ISRAEL

Z. REISS

The Hebrew University

During the past year, several students have been carrying on work on foraminifera toward their M.Sc. degrees, under the guidance of Professor M. Avnimelech and your correspondent. S. Greitzer and A. Golik have almost completed the mapping of two 1:20,000 sheets in the southern foothills region. This work is based to a large extent on the analysis of foraminiferal faunas from more than 1000 samples. The formations studied are of Cretaceous to Miocene age, and are generally developed in this area in a monotonous chalky facies, a fact which has greatly hampered earlier mapping work based on data other than micropaleontology.

L. Mor has started a study of the Nummulitidae of the Paleocene in the northwestern Negev, and L. Derin is making a detailed study of the planktonic foraminifera of the Paleocene in the same region. U. Berner is expected to investigate the subsurface formations of the northern Coastal Plain.

Geological Survey of Israel

Late in 1957 your correspondent was appointed head of the Paleontology Division of the G.S.I. During the past year, the Division underwent some reorganization, somewhat more emphasis being placed on mega-paleontology, in addition to increased activity in micropaleontology. Work continued on research projects initiated earlier, and new projects were started.

Intensive study of subsurface and surface formations of late Jurassic and early Cretaceous age continued, and a paper dealing with the stratigraphy of these strata in the Heletz oil field was published by P. Grader and your correspondent in January, 1958 ("On the Lower Cretaceous of the Heletz area," Bull. Geol. Survey Israel, no. 16). This work was mainly concerned with lithostratigraphy and with electric log and microfacies correlation. A more detailed account of the foraminifera studied in washed residues from wells in this area is in preparation, and will be published by your correspondent and Mrs. K. Klug early in 1959. Meanwhile, a large amount of new material from wells has been studied in cooperation with the Oil Division of the Geological Survey. Interesting data have been obtained on lateral facies-changes in connection with structure. The investigation of the Cenomanian – Turonian deposits of the country, carried out in cooperation with the G.S.I.'s Mapping Division, is proceeding rather slowly. In a short paper entitled "Remarks on the age of the so-called 'Dalia-marls' of Israel" (Bull. Geol. Survey Israel, no. 17), your correspondent reported the occurrence of *Helvetoglobotruncana helvetica* (Bolli) associated with megafauna (ammonites), indicating an early Turonian to possibly very late

Cenomanian age. A paper by P. Grader ("Geological outline of the Sasa region, Galilee," Bull. Geol. Survey Israel, no. 20) contains a list of foraminifera from the Senonian identified by your correspondent.

In a paper now in press, prepared by P. Grader in collaboration with your correspondent, it is shown that the marls containing *H. helvetica* (Bolli) occur only in certain localities in this country, and that their distribution is affected by the structure. This paper also contains well logs and remarks on Cenomanian foraminifera.

P. Grader and F. Moser have published a "Type composite log of the Upper Cretaceous and Lower Tertiary formations" (Bull. Geol. Survey Israel, no. 15), in which foraminifera identified by your correspondent from cores are listed. Outcrops in the Carmel Mountains area, mapped earlier as Cenomanian, have been shown by your correspondent to be of Miocene age (L. Picard and E. Kashai: "On the lithostratigraphy and tectonics of the Carmel," Bull. Res. Counc. Israel, vol. 7G, no. 1, 1958). They contain *Amphistegina*, *Ammonia*, and other forms. Your correspondent has completed a study of some 800 samples from the Nitzana area (northwestern Negev) from strata of late Cretaceous to late Eocene age. The results of this investigation will be published early in 1959, in collaboration with Y. Bentor, A. Vroman, and A. Parness, who mapped the area and determined the megafauna. The mapping of the area was based mainly on micropaleontological data. A study of the Oligocene and Neogene subsurface formations has been started by your correspondent, assisted by Mrs. P. Merling, in cooperation with the G.S.I.'s Oil Division. Emphasis is placed on the sequences of pelagic-planktonic foraminifera and on the statistical analysis of assemblages from cores that are virtually continuous through almost 400 meters. An attempt has been made to determine the conditions of sedimentation of these strata by micropaleontological, chemical and petrographic methods. D. Rabinowitz, who spent a year and a half in the United States

(Colorado School of Mines, University of Southern California, and elsewhere) studying problems of sedimentology as related to oil geology, is carrying out the lithologic work involved. Miocene foraminifera identified by your correspondent are listed by P. Grader in a paper on the Heletz area now in press.

Research has continued on the Quaternary deposits of the Coastal Plain, carried out in cooperation with the G.S.I.'s Hydrogeology Division and with T.H.L. (Water Planning for Israel). Plans are being made to publish part of the interesting results obtained so far. Excellent correlation has been found between the numerical composition of the foraminiferal assemblages and the heavy mineral counts from the respective samples. It appears that various strata previously regarded as being of "continental" origin are actually marine. This is shown both by the faunas occurring in them and by the composition of the heavy mineral assemblages. A significant correlation has been found between augite and hornblende and the occurrence of *Ammonia*. Of particular interest are the "wedge-outs" of marine strata and their interfingering with continental formations in relation to structure and shoreline position.

Your correspondent, in collaboration with Mrs. P. Merling, has continued his systematic studies of lamellar foraminifera. A short paper entitled "The systematic position of *Sigalia* and *Bolivinoides*" (Bull. Geol. Survey Israel, no. 17) has been published by your correspondent. It was shown that these two genera are not related, as had been claimed by some authors. A short paper on the structure of *Cibicides*, *Planulina*, *Gyroidinoides*, and *Globorotalites* will be published in MICROPALEONTOLOGY early in 1959. It deals with the systematic position of these genera on the basis of their wall structure. In a paper entitled "Structure of some Rotaliidea," now in press (Bull. Geol. Survey Israel), your correspondent and Mrs. P. Merling discuss some structural features of *Rotalia*, *Ammonia*, *Asterorotalia*, *Para-*

rotalia, *Calcarina*, *Cuvillierina*, and *Notorotalia*, and of the Rotaliidea in general, in the sense of Smout. Particular attention is paid to the toothplates, the septal flap, the various apertures, and the so-called canal system. The paper contains more than 70 photomicrographs of oriented thin sections to illustrate the features discussed.

Z. REISS
Paleontology Division
Geological Survey of Israel
Jerusalem

LIBYA

DAVID D. HUGHES

American Overseas Petroleum Company

K. Bordeau reports that Amoseas plans to move its paleontological laboratory into larger quarters in order to accommodate the increased volume of samples now being received. Much of his time at present is devoted to the difficult mechanical considerations involved in such a move.

Anglo-Saxon Petroleum Company Limited

The paleontological laboratory opened in May of 1958, and to date has been operating on a small scale. It is headed by Dr. W. H. Ruefli, stratigrapher. Dr. Ruefli worked for four years as an assistant in applied geology with Professor Dr. W. Leupold at the Federal Institute of Technology in Zürich, Switzerland. His thesis on Flysch investigations in the Swiss Alps is now in press. A junior paleontologist will arrive late in 1958.

d'Arcy Exploration (Africa), Inc.

Construction of the new paleontological laboratory was completed in July of 1958. It will be headed by Dr. W. H. Blow. Dr. Blow has worked previously in London and Malta.

Compagnie des Pétroles Total (Libya)

Paleontological operations were begun in December, 1957, when Miss J. Thibaut, head of the laboratory, came to Tripoli. She is assisted by M. Bourdon, who arrived in February, 1958. Their two main projects are a study of microfacies by the use of thin sections, and a study of the microfaunas of Libya. A mineralogical section is planned for the near future.

Esso Standard (Libya), Inc.

The paleontological section is expanding to include a new spore and pollen laboratory, which will house a larger hood for the new acid-extraction techniques. Dr. John Haynes is making a study of Cretaceous and Tertiary foraminifera from surface sections and well cuttings from northern Libya. Klaus Hoffmann, who has spent much time with Esso in both Turkey and Greece, is currently working on mega- and microfossils from Paleozoic sequences in the Fezzan (southwestern Libya) that he collected on a recent field trip into the Sahara. David Hughes was on home leave during August, 1958, and spent September and October in a training course at the Jersey Production Research Company in Tulsa, Oklahoma.

Dr. William S. Hoffmeister, of the Jersey Production Research Company, visited the laboratory early in 1958 to advise on the spore and pollen program. His aid in correlation and his advice on the new techniques was of invaluable assistance. Before returning to the United States, Dr. Hoffmeister spent some time visiting microfossil experts in Europe.

Mobil Oil of Canada, Limited

Don O. Nelson has returned from home leave in the United States. He has been in Libya for more than two years, and was one of the first paleontologists to arrive. Before this assignment he worked in South America for twelve years. Dr. Paul Arni, an expert on the Cretaceous and Tertiary of the Middle East, came here from Egypt in 1957. He is studying the regional stratigraphy of Libya, and has several research projects on the Upper Cretaceous, Eocene, and Miocene faunas. Don Nelson is studying the microfaunas from Mobil's wells, the macrofaunas of the surface sections, and the insoluble residues of the Libyan carbonates. The photographic laboratory is recording thin sections and an extensive collection of rock peels. A spore and pollen laboratory is planned for the near future.

Oasis Oil Company of Libya

A new research laboratory was set up in March, 1958, to deal with stratigraphic and paleontological problems. Dr. James S. Cullison and Samuel C. Johnson were transferred from the Sahara Petroleum operations in Alexandria, Egypt, to initiate the present program in Tripoli. They hope that in the near future the staff can be augmented by an additional paleontologist to cope with the many interesting problems which the active drilling program is uncovering.

DAVID D. HUGHES
Esso Standard (Libya), Inc.
Tripoli

POLAND

FRANCISZEK BIEDA

During the past year a number of papers on foraminifera and on spores and pollen have appeared in Poland. Miss S. Duszyńska (1958, Instytut Geologiczny, Bulletin, no. 121) published a note on three species of arenaceous foraminifera

found in Upper Carboniferous marginal sediments in the Upper Silesia basin. Mrs. O. Styk (1958, Inst. Geol., Bull., no. 121) presented a short note on a microfauna from the Polish Triassic, including a few foraminifera, Ostracoda, sponge spicules, and other organisms. For some time, Mrs. O. Pazdro has been conducting investigations on the foraminifera of the ore-bearing clays of the Middle Jurassic. She has recently published a paper (1958, Inst. Geol., Bull., no. 121) on this subject, concerning the species *Ophthalmidium carinatum*, of which she has described three new subspecies and defined their stratigraphic ranges.

The most noteworthy achievements in Polish micropaleontology have been concerned with Cretaceous foraminifera. Miss J. Sztejn (1957, Inst. Geol., Prace, vol. 22) is the author of a monographic work on the microfaunas of the Lower Cretaceous (Infravalanginian – Hauterivian) of central Poland. The material was derived from several places; particularly rich material was collected from the dark clays of Tomaszów Mazowiecki and Wąwał. The author described over 100 species, subspecies and varieties of foraminifera, among which ten are new, and fourteen species of Ostracoda, among which four are new. The foraminifera are mostly calcareous, only fifteen species being arenaceous. Miss Sztejn has demonstrated that the microfauna shows great similarity to that of the Lower Cretaceous of northern Germany. Another paper by the same author appeared in 1958 (Inst. Geol., Bull., no. 138), in Polish only, under the title "Key to the recognition of foraminifera in the Lower Cretaceous of central Poland."

Mrs. K. Pożaryska has also published a monograph, entitled "Lagenidae du Crétacé supérieur de Pologne" (Palaeontologica Polonica, no. 8, Warsaw, 1957). She has described nearly 200 species and subspecies occurring in the levels from Cenomanian to Lower Paleocene. The genera richest in species are *Lagena, Fissurina, Nodosaria, Den-*

talina, Astacolus, Marginulina, Lenticulina, Frondicularia, and *Palmula*; eight species and subspecies are new, belonging to the genera *Dentalina, Planularia, Lenticulina*, and *Frondicularia*. The author discusses the question of the genus *Tribrachia*, stating that this name should be suppressed as it was used to designate abnormal forms belonging to the genus *Frondicularia*. In this paper she also touches on other problems, such as the relationships of foraminifera to facies, the occurrence of racial groups ("Rassenkreise"), aberrant forms, regeneration, plastogamy, and the activities of parasitic microorganisms in foraminifera.

Several other authors have also written on the foraminifera of the Upper Cretaceous. Miss E. Witwicka (1958, Inst. Geol., Bull., no. 121) described thirty-seven species, subspecies, and varieties, including one new species, of foraminifera from a boring in Chełm. The fauna comes from a Cenomanian to upper Maestrichtian sequence. The genera most abundantly represented are *Bolivinoides, Stensioina*, and *Globotruncana*.

Mrs. E. Bieda (1958, Inst. Geol., Bull., no. 121) described twenty-seven species, one of which is new, from outcrops and shallow boreholes in the Upper Cretaceous (upper Campanian and lower Maestrichtian). This microfauna comes from Mielnik, on the Bug River in the Białystok region. The species occurring most frequently belong to *Neoflabellina, Bolivinoides, Stensioina*, and *Globotruncana*.

S. Alexandrowicz (1957, Polsk. Tow. Geol., Rocznik, vol. 26 (1956), no. 2) lists foraminifera from Upper Cretaceous marls that occur as large intramorainic boulders in the Pleistocene of Puszcza Bukowa (German: Finkenwalde), near Szczecin. The fauna is of lower Maestrichtian age, and consists of 105 species, mostly calcareous. In another paper, S. Alexandrowicz and W. Parachoniak (1958, Acta Geol. Polon., vol. 8, no. 2) have included two lists of foraminifera from the lower part of the upper Campanian of the Miechów syncline, in the Włosz-

czowa region between Kielce and Częstochowa.

A paper on the subject of Carpathian flysch foraminifera by S. Bukowy and S. Geroch (1957, Polsk. Tow. Geol., Rocznik, vol. 26 (1956), no. 4) is noteworthy. They have restudied the exposures at Kruhel Wielki, near Przemyśl. At this locality, gray marls occur between beds of conglomerate. According to K. Wójcik (1907), the microfauna of these beds was thought to be of lower Oligocene age, but the recent investigations of these authors have shown that the age is actually Maestrichtian. The foraminifera were identified by S. Geroch, who also described several species.

Miss J. Blaicher (1958, Kwartalnik Geologiczny, vol. 2, no. 2) lists arenaceous foraminifera from the Magura formation in the Grybów region. This unit includes several stratigraphic horizons; until now, foraminifera were known only from the younger stratigraphic levels, beginning with the Inoceramus beds of the uppermost Cretaceous. The author has established the presence of foraminifera in the older levels as well, that is, in the variegated shales and in the Szczawina sandstones, which, on the basis of their microfaunas, represent the interval from Albian to Turonian.

Lists of arenaceous foraminifera from the Cergowa series of the Dukla-Miechów folds are given by H. Jurkiewicz (1958, Przegląd Geologiczny, no. 6). This microfauna was collected near Dukla, south of Jasło. The age of the sediments is Eocene.

A list of calcareous foraminifera including seventy species, from the Paleocene of the outer margin of the Carpathians was given by F. Brotzen and K. Pożaryska (1957, Acta Geol. Polon., vol. 7, no. 4). This microfauna was obtained from a borehole in Boryszew, near Sochaczew.

In the most recent papers on the microfaunas of the Polish Miocene, only lists of foraminifera are given. Mrs. E. Łuczkowska (1958, Kwartalnik Geologiczny, vol. 2, no. 1) has published a paper on the foraminif-

eral fauna of the area between the Carpathians and the Święty Krzyż (Holy Cross) Mountains. The author distinguishes four changes in the sedimentation of the Tortonian. She gives photographs of the foraminiferal assemblages belonging to the four main periods, the highest or fourth of these assemblages perhaps including the lower Sarmatian in part.

The microfauna of the Tortonian in the Krakow area and Silesia was also determined by S. Alexandrowicz (1958, Kwart. Geol., vol. 2, no. 1). The existence of four separate levels of foraminiferal microfaunas in the Tortonian was confirmed in this study also.

On the basis of the above-mentioned papers by E. Łuczkowska and S. Alexandrowicz, the stratigraphic division of the Tortonian by microfaunas appears to be as follows: In the lower Tortonian (in Poland called the Opolian) there are two levels; there is one level in the middle Tortonian, which is named the Grabovian; and there is one level in the upper Tortonian, which is named the Buhlovian.

S. Alexandrowicz (1958, Acta Geol. Polon., vol. 8, no. 1) has published a list of foraminifera from the lower Tortonian (Opolian) of the Makoszowy mine in the Upper Silesia basin. This list comprises about 100 species of calcareous foraminifera, and several arenaceous species.

On the subject of micro-organisms other than foraminifera, a paper on Ostracoda has been published by F. Adamczak (1958, Acta Pal. Polon., vol. 3, no. 2). The author concludes that *Kozłowskiella* Přibyl, established originally as a subgenus of *Ulrichia*, is an independent genus. On the basis of material from the Middle Devonian of the Święty Krzyż (Holy Cross) Mountains, including both juvenile and adult specimens, the author has studied the ontogenetic stages of four species, three of which are new, and describes the evolution of these species during the Eifelian and Givetian.

Marked progress has taken place in research on microspores from the Upper Carboniferous of Poland. This work, as indicated in our last news report (Micropaleontology, vol. 4, no. 1), is being conducted by two scientists, Aleksander Jachowicz on the Polish side, and Mrs. Soňa Dybová on the Czechoslovakian side. The result of this collaboration of many years' standing is a large monograph entitled "Microspores of the Upper Silesian Coal Measures" (Inst. Geol., Prace, vol. 23, Warsaw, 1957), in which material from the Upper Carboniferous of Upper Silesia and adjacent areas in Czechoslovakia is described. This first monographic treatment of the microspores of the Upper Silesian coal basin appeared in the Polish and Czech languages, with short summaries in Russian and English. This work is important in stratigraphy, covering the geologic interval from the lower Namurian (strata of Petřkovice) to the upper Westphalian D (strata of Libiąż). One hundred thirty-six species and forms of microspores, belonging to forty genera and seventeen orders, are described. A number of these species, genera and orders appear here in the literature for the first time. There are ninety-one plates, and 185 tables in the text.

Problems of the stratigraphy of the Upper Silesian productive Carboniferous are presented by A. Jachowicz in another work (1958, Kwartalnik Geologiczny, vol. 2, no. 3). The author stresses the importance of microspores in the stratigraphy of the Upper Carboniferous of Poland, and states that microspores have proved their value as a means of identifying coal seams in exploitation. There are plates showing the most important species of microspores.

In another note (1958, Przegląd Geologiczny, no. 2), A. Jachowicz has reported the discovery of pollen of the genus *Entylissa* in the strata of Libiąż (Westphalian D) in the Upper Silesian coal basin. This genus had previously been reported only from the Donetz Basin and from Upper Carboniferous basins in northern Asia.

S. Dybová (1958, Kwart. Geol., vol. 2, no. 3) has discussed the importance of microspores in establishing the boundary between the Namurian and the Westphalian in the Ostrava-Karvina region. The work was based on material from Czechoslovakia, but the data are applicable to other parts of the Upper Silesian Basin, as well as to other basins.

Our knowledge of the megaspores of the Polish Upper Carboniferous is based on the work of J. Zerndt, which appeared between 1930 and 1939. Research in this field is being continued in Poland; Miss A. Brzozowska and Miss Z. Żołdani recently published a paper (1958, Kwart. Geol., vol. 2, no. 3) in which they gave the stratigraphic ranges of some types of Carboniferous megaspores occurring in the Upper Silesian coal basin and in other European basins. A note on sporomorphs from the Keuper of Świerczyna was published by Miss M. Pautsch (1958, Micropaleontology, vol. 4, no. 3).

Tertiary palynology is represented by a monograph published in Wrocław by S. Macko under the title "Lower Miocene pollen flora from the valley of Kłodnica near Gliwice (Upper Silesia)" (Wrocławskie Towarzystwo Naukowe, Prace, ser. B, no. 88, 1957). The author describes 181 species of pollen grains and spores, all known from plants now living. Fungi and diatoms were also found in the material described. The paper is illustrated with eighty plates.

Research on pollen occurring in Pleistocene sediments is being continued. Most of the recent papers on this subject appeared in a publication of the Geological Institute, under the general title "Quaternary researches in Poland, vol. 8" (1957, Inst. Geol., Bull., no. 118). Pollen from the Mindel-Riss interglacial stage of Gościęcin was the subject of a paper by A. Srodoń. In another paper, published in the Acta Societatis Botanicorum Poloniae (1957, vol. 26, no. 3), the same author reported the occurrence of pollen in the Riss-Würm interglacial stage of Koszary, on the Bug River.

Pollen of the Mindel-Riss interglacial stage has been described from Włodawa, on the Bug River, by Miss A. Stachurska, and from Maków Mazowiecki by Mrs. M.Gołąbowa. K. Bitner has reported the results of studies on pollen in interglacial floras from three localities in the vicinity of Sidra, north of Sokółka in the Podlasie region. The pollen comes from the Riss-Würm interglacial stage. Miss J. Oszast has given a history of climatic and vegetational changes in the late glacial stage and Holocene of the Dobrzyń region, based on pollen analysis.

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VENEZUELA

BOGUSŁAW J. SZENK

Compañia Shell de Venezuela

In April, 1957, preparatory work was begun on a study entitled "Microfacies of the Cretaceous of western Venezuela." The results will be published in the International Sedimentary Petrographical Series, under the auspices of Professor J. Cuvillier and Dr. H. M. E. Schürmann. The project is now near its conclusion. To date, about 5000 thin sections have been made and a considerable number of these sections have been described and photographed. Various microfacies types have been recognized and defined, and it has been possible to make good environmental inter-

pretations for some of them. The publication will contain approximately 120 photographs.

Creole Petroleum Corporation

After many years as head of Creole's Jusepín (Eastern Venezuela) laboratory, Gordon M. Sowers has been transferred to the Geological Department at Quiriquire. The new head of the Jusepín laboratory is Dr. R. M. Stainforth, previously with the Carter Oil Company at Billings, Montana. James L. Lamb, formerly with the Richfield Oil Company in California, has also joined the staff of the laboratory in Jusepín, and A. N. Dusenbury has been transferred to Creole's laboratory in Maracaibo. During the past year, Dr. Pedro J. Bermúdez has contributed extensively to the "Léxico Estratigráfico de Cuba," a unit of the "Lexique Stratigraphique International," which is now in press.

Mene Grande Oil Company

After acquiring large blocks of new concessions in Lake Maracaibo, the Mene Grande Oil Company decided to establish a palynological laboratory. The value of pollen grains and spores in correlating the Eocene in the Central Lake wells has been fully established by Shell's Maracaibo laboratory. In the first half of 1958, Mene Grande took definite steps toward the establishment of a pollen laboratory. George Fournier was put in charge of the project. A report outlining the techniques and procedures was issued, and a key well was chosen for the establishment of a type section. Samples from more than 2500 feet of section in the Eocene and Oligocene were washed, and more than 200 types were classified. Equipment for a modern air-conditioned laboratory has been ordered. Preparation of samples is currently being done in the Stratigraphic Laboratory, under rather difficult conditions. Dr. James E. Canright, a professor of palynology at Indiana University, has joined the recently established pollen section Meneg's Stratigraphic Labo-

ratory for a period of two month. He and a skilled assistant are aiding Mr. Fournier in the revision and establishment of Meneg's pollen and spore type collection.

Alejandro Euribe, a 1948 graduate of San Marcos University at Lima, Peru, recently joined the staff of Mene Grande's Stratigraphic Laboratory in Caracas. Prior to accepting this position, Mr. Euribe was employed as a micropaleontologist and stratigrapher for eight years by Empresa Petrolera Fiscal in Lima. From September, 1955, to June, 1956, Mr. Euribe was engaged in postgraduate studies at Stanford University, California.

Pan Venezuelan Oil Company

Dr. A. E. Wirz was recently named head paleontologist of the Pan Venezuelan Oil Company, with residence in Caracas. Dr. Wirz had previously been employed by the Cuban Stanolind Oil Company in Havana.

Venezuelan Atlantic Refining Company

Dr. Hans M. Bolli, a veteran paleontologist with Texaco Trinidad Inc. (formerly the Trinidad Oil Company), has accepted the position of Chief Paleontologist with the Geological Laboratory of the Venezuelan Atlantic Refining Company. This position was vacant for two years following Dr. Wolf Maync's resignation in 1956. Dr. Bolli's paper entitled "Planktonic foraminifera from the Cretaceous of Trinidad, B.W.I." is to be published by the Cushman Foundation for Foraminiferal Research. This study will be a supplement to his previous papers.

Consultants

Frank Amato has moved his paleontological laboratory to Las Mercedes, Calle Madrid, Edificio Désirée. He is currently installing the necessary laboratory equipment for initial pollen-research studies in the Maracaibo Basin.

BOGUSŁAW J. SZENK
Mene Grande Oil Company
Caracas